MEASUREMENT TECHNIQUES IN SOLAR AND SPACE PHYSICS MEETING PROGRAM

April 20-24 2015, NCAR Center Green Campus, Boulder, CO

PROGRAM CONTENTS

Monday, April 20, 8:30 - 19:00

1 8:30 - 10:15: PLENARY – Agency / Decadal [Auditorium]

Chair(s): J. Spann

1.1 8:30 - 8:45: Jim Spann & Thomas Moore: Introduction to MTSSP

1.2 8:45 - 9:15, *Invited*: Dan Baker: Measurement Technology Challenges: The 2013-2022 Decadal Survey in Solar and Space Physics

- University of Colorado LASP

The Space Studies Board of the U.S. National Academies established in 2011 a Steering Committee to develop a comprehensive science and implementation strategy for solar and space physics research. This updated and extended the Board's prior solar and space physics decadal survey, The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics (2003). The new Decadal Survey issued in 2012 broadly canvassed the field of research in solar and space physics to determine the current state of the discipline, identified the most important open scientific questions, and proposed the measurements and means to obtain them so as to advance the state of knowledge during the interval 2013-2022. The study implemented a 2008 Congressional directive to NASA for the fields of solar and space physics, but also addressed research in other federal agencies. Research in this field has sought to understand:

- the dynamical behavior of the Sun and its heliosphere;
- the dynamical behavior of the space environments of the Earth and other solar system bodies;
- the multiscale interaction between solar system plasmas and the interstellar medium; and
- energy transport throughout the solar system and its impact on the Earth and other solar system bodies.

Research in solar and space plasma processes also provides insights into analogous processes in more distant objects of astronomical interest. In addition, great strides in research equipment and data systems, theory, and numerical models have offered the prospect of understanding this interconnected system well enough to develop a predictive capability for operational support of civil and military needs and systems. This presentation will describe the recommendations and strategic plans laid out in the 2013-2022 Decadal Survey as they relate to measurement capabilities and new detection techniques. The talk will assess progress to date in these domains and recommend further steps to achieve the Decadal Survey goals.

1.3 9:15 - 9:45, *Invited*: Jeffrey Newmark: NASA Technology Development Programs

- NASA Headquarters

1.4 9:45 - 10:15, *Invited*: Therese Moretto Jorgensen: Measurement Technology Challenges: the NSF Geospace Perspective

- National Science Foundation

The Geospace Section (GS) of the Division of Atmospheric and Geospace Science at NSF supports basic research to advance our understanding of solar and space physics, especially pertaining to the near-Earth space environment. Expansion of geospace observing capabilities has been ongoing for many years and has been a cornerstone of the section's research program. Observing facilities supported by GS now include six incoherent scatter radars, a global network of SuperDARN radars, the Consortium for Resonance and Rayleigh Lidars, and the Low-Latitude Ionospheric Sensor Network. Space-based capabilities, such as AMPERE and CubeSat missions provide complementary coverage of geospace domains.

A comprehensive portfolio review for GS was launched in March 2015. The review is motivated, in part, by the priorities highlighted in the 2013 National Research Council's Decadal Survey Report, Solar and Space Physics – A Science for a Technological Society, and to carry out stewardship of the overall Geospace research program and ensure the best scientific return within an allocated budget. The primary goal of this review, and of any resulting adjustments of the GS portfolio, is to ensure that investments in the GS science disciplines and respective facilities are properly aligned, both now and in the future, with the needs and priorities of the Geospace scientific community, in part as articulated in the Survey. Input into the review from the larger Geospace Research community is welcomed and encouraged.

2 10:30 - 12:15: PLENARY – Photons (#1) [Auditorium]

Chair(s): S. Christe

2.1 10:30 - 11:30, *Invited*: Jonathan Cirtain: Perspectives on the next generation in space-based solar remote sensing

- NASA MSFC

Improvements in fabrication techniques for multiple technologies necessary for increases in signal to noise and resolution increases offer extension and invention of remote sensing instruments. Mirror fabrication and polishing, the manufacture of new spectroscopic dispersive optical elements, and improved performance of focal plane detectors are being combined resulting in substantial instrumentation throughput. The MSFC Heliophysics group and its partner institutions are actively involved in the design, fabrication and testing of several sounding rocket experiments. These instruments employ several advancements in fabrication and performance validation. Instrumentation for UV spectropolarimetry, EUV imaging and x-ray imaging spectroscopy will be introduced.

2.2 11:30 - 12:15, *Invited*: Gordon Holman: Scientific Considerations for Future Spectroscopic Measurements of Activity on the Sun from Space

- NASA GSFC

High-resolution spectroscopy is important to understanding the origin and evolution of magnetic energy release in the solar atmosphere and the subsequent evolution of heated plasma and accelerated particles. With plasma temperatures ranging from about ten-thousand K to above 10 MK, accelerated electrons emitting photons at keV X-ray energies and ions emitting in gamma-rays, space-based instruments observing at frequencies in the far UV and higher are required. To follow the evolution of solar activity, imaging spectroscopy with a cadence of seconds or better is needed. I will discuss specific examples of why this is important. I will also discuss some current observations and what they indicate is needed for the future. The major challenge will be, within the bounds of existing technologies and funding, to conceive instruments that have the flexibility and field of view to obtain observations where and when events occur while providing an optimum balance of dynamic range, spectral resolution and range, and spatial resolution.

3 13:15 - 15:00: PLENARY – Fields (#1) [Auditorium]

Chair(s): R. Pfaff & B. Anderson

3.1 13:15 - 13:50, *Invited*: Forrest Mozer: How to measure DC electric fields

- University of California - Berkeley

The technique for measuring DC electric fields seems simple because it consists only of measuring the potential difference between two separated conductors. However, the measured potential differences are small compared to the variety of errors that can occur. This talk focuses on such error sources and how to be aware of them and limit them as much as possible.

3.2 13:50 - 14:25, *Invited*: Hermann Lühr: Recent Progress in DC Magnetic Field Measurement and Analysis

- GFZ, German Research Centre for Geosciences

Co-author(s): Jose Merayo[1], Peter Brauer[1], Fan Yin[2], Patrick Alken[3]
- [1] Technical University of Denmark, [2] Wuhan University, [3] National Geophysical Data Center NOAA

Much progress in the development of DC magnetometers has been achieved in connection with the magnetic field mapping missions: Ørsted, CHAMP, and Swarm. This is true both for vector instruments, fluxgate magnetometers and scalar magnetometers, e.g. Helium vapour instruments. In this talk we focus on fluxgates. There are three issues that need special attention: instrument noise, linearity, and sensor stability. For all of them satisfying solutions have been found. We are reporting primarily about the experience gathered from the fluxgate on CHAMP during its 10-year mission. Within the full field range ($\pm$65,000 nT) the noise was in the 10 pT range. The offsets of the three components were stable after the early burn-in months within 0.5 nT. Particularly outstanding is the stability of the angles between the sensor axes. The values stayed the same within 1 arcsec over all the years and showed no temperature dependence. This overall success has been achieved by the use of suitable core material (here amorphic magnetic ribbon) and the application of the compact spherical shell around the sensor elements.

Precise magnetic field mapping from space requires readings with absolute accuracy over many years. In order to achieve that calibration procedures have to be applied in space and disturbances from the spacecraft corrected. The standard procedure for non-spinning spacecraft is the scalar calibration. In that case the nine instrument parameters of the fluxgate (3 sensitivities, 3 offsets, 3 alignment angles) are determined by matching the total field readings between the fluxgate and the absolute scalar magnetometer. However, this technique works well only when disturbances from the spacecraft have been corrected beforehand. In case disturbances can be parameterised (e.g. by HK data), they can be co-estimated as part of the calibration.

Present-day geomagnetic field models are so reliable that they can also be used for calibration and correction of instruments on LEO satellites. A very promising example for that is the Earth's magnetic field model derived from DMSP magnetometers (Alken et al., 2014).

3.3 14:25 - 15:00, *Invited*: Roy Torbert: Electromagnetic Field Measurements in Rarified Plasmas using the Electron Drift Instrument.

- University of New Hamphsire & Southwest Research Institute

Co-author(s): Hans Vaith, Craig Kletzing
- University of New Hampshire, University of Iowa

Measurements of magnetic and electric field measurements from spacecraft in rarified plasmas are complicated by the disturbances induced by the presence of the spacecraft itself. Since remote sensing of these fields is not possible in most cases, every effort is made to reduce the effects of these disturbances, including heroic magnetic and electrostatic cleanliness programs. In the case of the electric field whose measurement is the most difficult, specific construction of controlling electrodes and bias current systems is required to reduce systematic errors in the double probe technique. The Electron Drift Instrument (EDI) on both the Cluster and MMS missions was flown to provide an alternative method which is not susceptible to these effects. The EDI technique however can provide only a relatively low cadence of samples and has limitations of its own in terms of ambient perturbations. Nevertheless, on MMS, the EDI measurements in combination with more conventional techniques will be critical to providing electric and magnetic field of high enough accuracy to move our understanding of reconnection forward, This talk will describe the EDI technique and how MMS will use its accuracy to provide this high quality data.

4 15:15 - 17:00: PARALLEL SESSIONS – Ground, Particles, Photons

4.a Ground – Magnetometers / VLF / Optical [North]

Chair(s): I. Mann

4.a.1 17:15 - 17:35, *Invited*: Marc Lessard: Recent Advances in Fluxgate Magnetometer Developments

- University of New Hampshire

Co-author(s): Paul Riley[1], Barry Narod[2], Roy Torbert[1], Chrystal Moser[1]
- [1] *University of New Hampshire,* [2] *Narod Geophysics*

Magnetic field measurements in space science have been made for centuries. On the ground, magnetometers measure field perturbations associated with ionospheric currents and a wide range of wave phenomena that couple from the magnetosphere through the ionosphere to the ground. Instrument sensitivity limits the extent to which so-called "equivalent ionospheric currents" can be estimated in cases where the ionospheric currents are weak and/or when the ground stations are far from the source. Sensitivity also limits observations of wave signatures (e.g., ion cyclotron waves) such that induction coil magnetometers are often used side-by-side with fluxgates because they have improved performance at the relevant frequencies. Recent efforts have focused on developing a new sensor with a noise floor that exceeds currently available designs (below 3 pT/$\sqrt{\text{Hz}}$ at 1 Hz), a noise floor that competes with induction coil magnetometers. Improved performance can be expected to reduce or eliminate the need for supporting both fluxgate and induction coil magnetometers at a single location. Other efforts are aimed at developing an instrument specifically for use on cubesats, an application that requires low power, low mass and low cost. Trading off sensitivity, we have been able to produce a 2x2x2 cm sensor that requires only 360 mW and has a sensor mass of 15 grams. Further refinements in the performance of this sensor are underway, with the goal of reducing the size even further, while providing an acceptable noise floor.

4.a.2 17:35 - 17:55, *Invited*: Robert Moore: Ground-based ELF/VLF observations in Antarctica

- University of Florida

Co-author(s): Michael Mitchell
- University of Florida

The Ionospheric Radio Lab at the University of Florida has been intimately involved in Antarctic research since 2010. Over the last four years, our research group has operated extremely low frequency (ELF, 5-3000 Hz) and very low frequency (VLF, 0.5-30 kHz) radio sensors at the three Antarctic US research bases (McMurdo, South Pole, and Palmer Stations). Our mission goal is to study radio wave propagation around the globe and in near-Earth space using radio observations made in the quiet Antarctic environment.

The Antarctic bases are ideally situated for our instruments to detect solar X-ray flares, particle precipitation from the Earth's radiation belts, and rare proton injection events that occur during strong solar storms. In this sense, our research is strongly coupled with NASA's and NSF's Space Weather monitoring efforts.

These stations are also ideal for studying the electromagnetic waves radiated by lightning. We study the effects of natural lightning on the near-Earth space environment, we perform rocket-triggered lightning experiments at the International Center for Lightning Research and Testing (in Starke, FL), and we detect the effects in polar regions.

This talk will introduce the Ionospheric Radio Laboratory and provide an overview of our ongoing Antarctic experiments. We will focus on the hardware specifications of our ELF/VLF receivers, and discuss possible future research directions.

4.a.3 17:55 - 18:08: János Lichtenberger: Ground based Very Low Frequency Measuring Networks

- Eötvös University

Co-author(s): Anders Jörgensen, Csaba Ferencz, Péter Szegedi, Mark Clilverd, Craig Rodger, Bob Holzworth, James Brundell
- New Mexico Institute of Mining and Technology, Eötvös University, BL Electronics, British Antartic Survey, Otago University, University of Washington, UltraMSK.com

In this paper we present three Very Low Frequency (VLF) measurements techniques used in Space Physics and Space Weather investigations. The first technique is a ground based broad band VLF measurements. As the first Measurement Techniques in Space Plasmas volumes do not include ground based technique, we briefly describe the classic VLF measurement principle used to record various VLF phenomena: whistlers, choruses, hisses, triggered emissions, etc. This technique has been further developed recently using magnetic search coils in Automatic Whistler Detector and Analyzer Network (AWDANet). The global AWDANet network is able to use broad band VLF measurements to detect and analyze VLF whistlers to infer plasmaspheric electron densities in quasi real-time. The obtained density data are fed to a data assimilative model of the plasmasphere.

Monitoring the phase and amplitude perturbations of military VLF transmitters by narrow band VLF measurements is another technique. It is used by the Antarctic-Arctic Radiation-belt (Dynamic) Deposition - VLF Atmospheric Research Konsortium (AARDDVARK) network to monitor relativistic electron precipitation from the radiation belts. However, this technique can also be used to monitor the classic 'trimpi' effect (whistler induced electron precipitation), the response of ionosphere to solar flares and solar proton events, the transient luminous events (sprites, elves) related changes in ionization between thunderstorm clouds and ionosphere.

The third VLF measurement technique is also measures broad band VLF signal to locate lightnings. The World Wide Lightning Location Network consist of a few tens of measuring nodes worldwide only and able to locate lightning and monitor the global lightning activity.

4.a.4 18:08 - 18:21: Eftyhia Zesta: The dynamics of the plasmasphere and its boundary layer remotely determined by ground magnetometers

- NASA GSFC

Co-author(s): P. Chi, A. Boudouridis, E. Yizengaw, M. Moldwin, I. Mann

- UCLA, Space Science Institute, Boston College, University of Michigan, University of Alberta

Ground-based magnetometers can monitor the dynamic plasmasphere through the use of the normal-mode magneto-seismic technique, which infers the equatorial plasma mass density from the field line resonance (FLR) frequencies detected on the ground. The remote monitoring of the plasmasphere and the plasmasphere boundary layer (PBL) can be a powerful and continuous monitoring tool. We merge data from many ground magnetometer pairs from the SAMBA (South American Meridional B-field Array), McMAC (Mid continent Magnetoseismic Chain), and CARISMA (Canadian Array for Realtime Investigations of Magnetic Activity) chains to provide the best available spatial coverage in L values spanning the plasmasphere and PBL, for a range of dynamic states (L=1.6 to greater than 5). The PBL location is identified as the L value of the station pair for which a reverse phase difference is observed in the standard FLR determination. We also present equatorial plasma density derived from the geomagnetic field observations collected by AUTUMN/AUTUMNX, CARISMA, Falcon, GIMA, McMAC, THEMIS, and USGS stations in North America. The FLR-inferred equatorial plasma mass density covers the region with equatorial distances between 1.5 and 8 RE and a span of local time for up to 6 hours, and a snapshot of this density distribution is made with every 10 minutes of magnetometer data. We will present examples that demonstrate the spatio-temporal variations of the plasmasphere in response to solar activity.

4.a.5 18:21 - 18:34: Endawoke Yizengaw: The ULF Wave Related Fluctuation of Equatorial Electrodynamics and Its Longitudinal Variability

- Boston College

Co-author(s): Eftyhia Zesta, Mark Moldwin, Russell Stoneback
- NASA GSFC; University of Michigan; University of Texas - Dallas

We applied a new data visualization technique to multi-instrument observational data to understand the contribution of the ULF wave in the fluctuations of equatorial electrodynamics and density. We found that the magnetospheric Alfvén waves, like ULF wave in the Pc5 range, are very much intense enough to modulate equatorial ionospheric electrodynamics and cause density fluctuation. While the formation of equatorial electrojet (EEJ) and its temporal variation is believed to be fairly well understood, the longitudinal variability at all local times is still unknown. This paper presents a case and statistical study of the longitudinal variability of dayside EEJ for all local times using ground-based observations. The presence of similar significant longitudinal difference is also confirmed on the dusk sector pre-reversal drifts (using the ion velocity meter (IVM) instrument onboard the C/NOFS satellite). We found that the magnitude and direction of the vertical drift (both dayside and evening sector) show significant longitudinal differences, stronger in the American and Asian than African sectors. On the other hand both ground- and space-based observations show clear longitudinal and seasonal variability of bubbles/irregularities structures, stronger and active all year round in the African sector, which is opposite to the vertical drift longitudinal variability trend. This study raises several questions. If not the drift, which is believed to be the main cause for the enhancement of Rayleigh-Taylor (RT) instability growth rate, that cause the longitudinal bubbles distribution difference, then what could it be? Would it be the neutral winds that cause the long lasting bubbles in Africa? If it is the neutral wind, why the orientation and magnitude of the wind in the African sector is unique compared to other longitudes?

4.a.6 18:34 - 18:47: Asti Bhatt: A network of ground-based red-line optical imagers in continental United States: Initial data and future plans

- SRI International

Co-author(s): Elizabeth Kendall
- SRI International

A network of 630 nm all-sky imagers in the continental United States is being designed to observe generation, propagation, and dissipation of medium and large-scale wave activity in the subauroral, mid and low-latitude thermosphere and sustained investigation of the Stable Auroral Rec (SAR) arc. This network will ultimately consist of 8 all-sky imagers including four existing imagers. Combining the field-of-view from this network with the field-of-view from the Canadian network of REGO red-line imagers will create a contiguous red-line image in the American sector spanning the polar cap, auroral zone, subauroral, mid and low-latitudes. This network will overlap with the field-of-view of the NASA GOLD mission in north America. Four of the imagers are currently operational, with two operated by SRI International and two by Boston University. Since an all sky red-line camera images the ionospheric altitudes between 250 and 350 km, three of the installed imagers form a network providing continuous coverage over the western United States, from Washington state to southern Texas extending into northern Mexico. This network sees high levels of both medium and large scale wave activity, often with structures spanning multiple fields-of-view. Apart from the widely reported northeast to southwest propagating wave fronts resulting from the so called Perkins mechanism, this network observes wave fronts propagating to the west, north and northeast. The observed wave activity has been associated with thunderstorms in the lower atmosphere or auroral precipitation at high latitudes. We will describe the specifications of the imagers and the proposed imager network as well as show data from the current network of western US imager network.

4.a.7 18:47 - 19:00: Emma Spanswick: The Redline Emission Geospace Observatory (REGO) all-sky imaging array - system design and initial results

- University of Calgary

Co-author(s): Eric Donovan, Craig Unick, Brian Jackel, Megan Gillies, Darren Chaddock, Neil McGuffin, Patricia Groves
- University of Calgary

The Redline Emission Geospace Observatory (REGO) all-sky imager network consists of nine highly sensitive, 630nm narrow band imagers deployed across Central and Northern Canada. The array is designed to provide contiguous imaging of low energy (several eV to keV) electron precipitation from deep in the polar cap to subauroral latitudes. Operating at a 3s cadence with <1km resolution at zenith, REGO provides the first simultaneous observations of detailed structure and dynamics in the polar cap, auroral zone and subauroral latitudes. Further, the array shares much of its observational volume with the THEMIS-ASI white light array allowing for simultaneous observations and in some cases, isolation of low energy electron dynamics. In this paper, we present an overview of the REGO system design and performance, as well as first light observations during various types of auroral events (quiet time, substorm, etc.). Our initial observations reveal highly dynamic redline auroral structures throughout much of the night side; even in the absence of visible (white light) aurora. We also show clear examples of coupling between geospace regions (polar cap and auroral zone). We anticipate that the REGO data will provide key information to studies of system level geospace coupling, particularly in the upcoming era of magnetospheric satellites.

4.b Particles – Composition [Center]

Chair(s): G. Earle, J. Clemmons

4.b.1 15:15 - 15:35, *Invited*: Stefano Livi: Gas Composition Analyzers

- Southwest Research Institute

Knowledge of the chemical composition of gaseous environments is of paramount importance for the understanding of the origin and evolution of the orbiting gas around a central object as well as of those of the parent body. Chemical elements and compounds act as tracers of the processes generating and modifying the environment of a planetary body, and their interaction with the surface is responsible for modification and aging of the surface. A clear example is the atmosphere of Mars, where the stripping produced by the solar wind interaction with the atmosphere/ionosphere has, during billions of years, modified the surface water content of the whole planet.

The *in-situ* analysis of atmospheres (collision dominated) and exospheres (ballistic) necessarily needs to span a large range of densities (ranging for example from the very dense atmosphere of Jupiter to the extremely thin exosphere of Mercury) and variety in chemical composition (from the simple, mostly atomic chemistry of Mercury to the very complex organic compounds surrounding comets or Titan).

This delineates the need of very different instruments to properly study the environment at hand: mass spectrometers and spectrographs have been flown and are currently being prepared for measuring the composition of the gas envelops around many bodies of the solar system. The requirements for the analyzers, the design approach taken, the results (when available) will be all discussed and compared to each other.

4.b.2 15:35 - 15:55, *Invited*: Dominique Delcourt: The Mass Spectrum Analyzer (MSA) onboard Bepi Colombo MMO

- LPP (France)

Co-author(s): Y. Saito, F. Leblanc, C. Verdeil, S. Yokota, M. Fraenz, H. Fischer, D. Fontaine, B.

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- ISAS JAXA, Max Plank Institute, IDA

Observations from the MESSENGER spacecraft have considerably enhanced our understanding of the plasma environment at Mercury. In particular, measurements from the Fast Imaging Plasma Spectrometer (FIPS) provide evidences of a variety of ion species of planetary origin (He+, Na+) in the northern dayside cusp and in the nightside plasma sheet. A more comprehensive view of Mercury's plasma environment will be provided by the Bepi Colombo MMO (Mercury Magnetospheric Orbiter) spacecraft that will be launched in 2016. Onboard this spacecraft, the MPPE (Mercury Plasma/Particle Experiment) consortium gathers different sensors dedicated to particle measurements. Among these, the Mass Spectrum Analyzer (MSA) is the instrument dedicated to composition analysis. It consists of a top-hat for energy analysis followed by a Time-Of-Flight (TOF) section to derive the ion mass. A notable feature of the MSA instrument is that the TOF section is polarized with a linear electric field that leads to isochronous TOFs and enhanced mass resolution (typically, M/dM >40), a capability that is of importance to thoroughly characterize ion species originating from Mercury's exosphere. Taking advantage of the spacecraft rotation, MSA will provide three-dimensional ion distribution functions in one spin (4 s), from energies characteristic of exospheric populations (a few eVs or a few tens of eVs) up to the plasma sheet energy range (up to about 40 keV/q). A review of MSA performances will be presented.

4.b.3 15:55 - 16:08: Mihir Desai: Compact Dual Ion Composition Experiment for Space Plasmas —CoDICE

- Southwest Research Institute

Co-author(s): K. Ogasawara, R. W. Ebert, D. J. McComas, F. Allegrini, S. E., Weidner, N. Alexander, and S. A. Livi
- Southwest Research Institute

We have developed a new, versatile, fully integrated Compact Dual Ion Composition Experiment — CoDICE — that simultaneously provides high quality plasma and energetic ion composition measurements over 6 decades in ion energy in a wide variety of space plasma environments. CoDICE measures the two critical ion populations in space plasmas, namely: 1) Elemental, isotopic, & charge state composition, and 3D velocity & angular distributions of $\sim$10 eV/q—40 keV/q plasma ions; and 2) Elemental & isotopic composition, and energy spectra & angular distributions of $\sim$30 keV—10 MeV energetic ions. CoDICE uses a common time-of-flight subsystem that requires significantly less mass and volume compared with two separate instruments, requires less shielding in high radiation environments because of excellent signal-to-noise ratio, and simplifies spacecraft interfaces and accommodation requirements. CoDICE provides several advantages over two separate plasma and energetic ion sensors currently flying on numerous deep space flight missions such as the Van Allen Probes. This paper describes the design principles, ray tracing simulations, laboratory prototype testing, and proof-of-concept validation of the CoDICE concept, as adapted for measuring magnetospheric and solar wind plasma, pickup, and energetic ion populations expected to be present in the Earth's radiation belts.

4.b.4 16:08 - 16:21: M.E. Hill: The Mushroom: A Half-Sky Time-of-Flight Mass Spectrometer for Energetic Ion and Electron Detection

- Johns Hopkins University APL

Co-author(s): D.G. Mitchell, G.B. Andrews, S.M. Begley, M.P. Boyle, A.R. Dupont, J.R. Hayes, R.S. Layman, R.L. McNutt, Jr., K.S. Nelson, C.W. Parker, H. Seifert, M.R. Stokes, J.D. Vandegriff
- Johns Hopkins University APL

We present a time-of-flight (TOF) mass spectrometer design for the measurement of ions in the $\sim$30 keV/nuc to $>$10 MeV/nuc range and $\sim$30 keV to 1 MeV electrons, covering half of the sky (2π steradians) with 80 apertures. The instrument is dubbed the Mushroom for its dome-shaped arrangement of eight sensor heads and supporting, stem-like electronics box. It was first developed for flight for NASA's Solar Probe Plus mission as the EPI-Lo (Energetic Particle Instrument-Low Energy) instrument, composing half of the ISIS (Integrated Science Investigation of the Sun) energetic particle suite. It is suitable for magnetospheric and heliospheric missions, especially those that require extended angular coverage but employ three-axis stabilized spacecraft, however a spinning spacecraft is also fully compatible. The ion and electron measurements rely on solid-state detectors (SSDs) for energy determination and the ion measurement additionally employs micro-channel plates (MCPs) and secondary-electron-emitting foils for the TOF determination, both techniques having decades of heritage. The most important new feature of the Mushroom is the method through which electrostatic optics and position sensing combine to permit many apertures to fit into a compact, low-mass sensor head (or wedge). A primary (foreground) ion enters the wedge, passing through one of the ten start foils, through the single stop foil, and then is stopped in the SSD. Secondary electrons produced at the surfaces of the foils are guided electrostatically from their points of emission to the MCP assembly. The start electrons are accelerated toward one of ten small active regions of the MCP, which, when combined with delay line electronics, permits determination of the entrance aperture. The stop electrons are electrostatically reflected to strike a designated stop region on the MCP. A start and stop signal with a fixed path length yields a speed, which, together with the position sensing, yields a vector velocity. Combined with the SSD energy, the ion mass is determined. The primary electron measurement will rely only on the SSD for energy and positional information and aluminum flashing to suppress competing ion contamination. Most of the sensor volume containing the primary and secondary particle trajectories is an empty, equipotential volume, resulting in the modest 210g mass of each ten-aperture wedge. The Mushroom is capable of separating ion species with a typical full-width-half-max mass resolution of $\sim$0.75 times the difference in atomic mass units between a given species and its neighboring species (depending on mass and energy). This permits separation of He-3 and He-4 isotopes, a capability that was critical for the EPI-Lo instrument development.

4.b.5 16:21 - 16:34: Jason Gilbert: The Pickup Ion Composition Spectrometer

- University of Michigan

Co-author(s): Thomas H. Zurbuchen, Steven Battel
- University of Michigan, Battel Engineering Inc.

Newly ionized atoms from planetary sources that are picked up by the solar wind and carried into the heliosphere contain information on the plasma and dust compositions of their origin. These pickup ions (PUIs) are collected by plasma mass spectrometers and analyzed for their density, composition, and distribution in both energy and velocity. In addition to measurements of planetary PUIs, *in situ* measurements of interstellar gas have been made possible by spectrometers capable of differentiating between heavy ions of solar and interstellar origin. While fascinating research has been done on these often singly charged ions, the instruments that have detected many of them were designed for the energy range and charge states of the solar wind and energized particle populations. An instrument optimized for the complete energy and time-of-flight characterization of pickup ions will unlock a wealth of data on these hitherto unobserved or unresolved PUI species. The Pickup Ion Composition Spectrometer (PicSpec) is one such instrument, and will enable the next generation of pickup ion and isotopic mass composition spectrometers. By combining a large-gap Time-of-Flight—Energy sensor with a negative 100-kV high voltage power supply for ion acceleration, PUIs will not only be above the detection threshold of solid-state energy detectors, but also resolved sufficiently in time-of-flight that isotopic composition can be determined. This technology will lead to a new generation of space composition instruments, optimized for measurements of planetary pickup ions, yet applicable to pickup ions in the solar wind as well.

4.b.6 16:34 - 16:47: Elizabeth MacDonald: Recent advances in plasma mass spectrometry

- NASA GSFC

Co-author(s): D. Chornay, G. Collinson, H. Funsten, D. Gershman, R. Harper, B. Larsen, T. Moore, C. Pollock, R. Skoug
- NASA GSFC, Los Alamos National Lab

Carbon foils and time of flight techniques have been used on a number of satellite and rocket instruments to measure ion composition in the plasma energy regime (from a few eV up to $\sim$ 50 keV). Recent advances have pushed these techniques to use lower resources and study more extreme environments. This presentation will highlight two new advances in plasma mass spectrometry. One, the use of an array of channel electron multipliers with carbon foils in a background of extreme penetrating radiation has proved successful with the two year plus mission of the Van Allen Probes and the Helium, Oxygen, Proton, Electron (HOPE) spectrometers. Secondly, a new instrument concept aimed at the tenuous, very low energy plasma of the Earth's high latitude ionosphere at altitudes from the peak of the F region to the exobase is discussed. In this design, an electronic gate would be used as an alternative to a carbon foil which would be prohibitively difficult in this environment. The gate also allows the sensitive dynamic range of the instrument to be varied. Both implementations will be discussed along with illustration of the desired or measured instrument response, spacecraft accommodation, and other issues which can affect sensitivity.

4.b.7 16:47 - 17:00: Thomas Moore: Obtaining a 3D View of Ionospheric Pick-Up Ions

- NASA GSFC

Co-author(s): G A Collinson, D J Gershman, E A Macdonald, C J Pollock
- NASA GSFC

A 3D view of ionospheric pick-up ions is necessary if we are to successfully validate and further develop theories of the creation of pick-up velocity distributions, as originally predicted in 1979 by St.-Maurice and Schunk. Incoherent Scatter Radars have recorded evidence of "non-thermal" velocity distributions that were interpreted as "toroidal" or pick-up distributions. However, these observations were not fully definitive and have been met with skepticism to some degree. Pick-up distributions are thought to be unstable to the growth of plasma waves that serve to thermalize their free energy, and may be an important source of such waves in the auroral ionosphere. This may contribute to our understanding of the broadband ELF waves thought to heat ionospheric ions and drive their outflow into the magnetosphere. We describe an instrument concept based on the Fast Plasma Instrument developed for the Magnetospheric Multiscale Mission, augmented by an electrostatically gated TOF system to determine ion composition. This system can be varied continuously in mass resolution to adjust its sensitivity, enhancing its dynamic range substantially. When mounted in alignment with the spin axis of a cartwheel spacecraft, it is capable of continuously measuring the properties of the rammed core plasma as well as observing non-thermal creation of pick-up ion distributions in the energetic tail of the core distribution, and determining their degree of thermalization from initial pick-up.

4.c Photons – Spectroscopy [South]

Chair(s): S. Bandler

4.c.1 15:15 - 15:45: Leonard Strachan: Remote Sensing of Coronal Suprathermal Seed Particles involved in Solar Energetic Particle Acceleration

- Naval Research Laboratory

Co-author(s): J. Dan Moses, Yuan-Kuen Ko, J. Martin Laming, Samuel Tun Beltran
- Naval Research Laboratory

Solar Energetic Particles (SEPs) are a known hazard to spacecraft systems, astronauts in space, and even aircraft traveling along polar routes. At the present, despite many attempts to do so, there are no means to provide long-term warning of either the timing or magnitude of SEP events. One such method for early warning detection is to search for the presence of high energy seed particle populations near the sun that may be involved in the production of SEPs during the passage of a coronal shock. This technique requires very accurate measurements of the shape of emission line profiles observed in the solar corona. Suitable coronal lines for this diagnostic include H I Lyman alpha, O VI 103.2 nm, and possibly other bright coronal lines. In this paper, we describe how measurements of the seed particle properties, combined with remote sensing measurements of coronal shocks, may be used for a future predictive capability that provides advanced warning for SEPs. The Naval Research Laboratory is pursuing these ideas for a future mission that will have the capability to make all of the required measurements for a SEP warning system.

This work is funded by the NRL basic research program (CNR) and NASA through NDPR NNG13WF95I.

4.c.2 15:45 - 16:00: Simon Bandler: X-ray microcalorimeters for solar physics

- NASA GSFC

Within the X-ray microcalorimeter group at NASA/GSFC we are developing small-pixel transition-edge sensor microcalorimeters for solar physics and astrophysics applications. These large format close-packed arrays are designed to have high energy resolution, and also accommodate count-rates of hundreds of counts per second per pixel for X-ray photon energies up to 8 keV. We have fabricated kilo-pixel versions that utilize narrow-line planar and stripline wiring. We present measurements of the performance of pixels on a 50-μm and 75-μm pitch. With individual single pixels of this type, we have achieved a full-width at half-maximum energy resolution of 0.7 eV with 1.5 keV Al K X-rays, and under 1.6 eV with 6 keV MnK X-rays. This type of performance can provide a velocity resolution of 80 km/s. An instrument incorporating a large array of pixels of this type, with a modest X-ray mirror, would provide simultaneous arcsecond-scale imaging and high-resolution spectra over a field-of-view sufficiently large for the study of active regions and flares. Such an instrument would make possible a wide range of investigations such as the detection of microheating in active regions, ion-resolved velocity flows, and the presence of non-thermal electrons in hot plasmas. The properties of our current microcalorimeter arrays and the potential for further development will be discussed and also their application to new solar mission concepts.

4.c.3 16:15 - 16:30: Kenneth Dymond: The High Resolution Ionospheric and Thermospheric Spectrograph (HITS) on the Advanced Research and Global Observing Satellite (ARGOS)

- Naval Research Laboratory

Co-author(s): Scott Budzien
- Naval Research Laboratory

The High–resolution Ionospheric and Thermospheric Spectrograph (HITS) was a very high resolution (>0.5 Å resolution over the 500-1500 Å passband) Rowland circle spectrograph that flew on the USAF Advanced Research and Global Observing Satellite (ARGOS). ARGOS launched from Vandenberg AFB, CA on 23 February 1999. The ARGOS was in a sun-synchronous, near-polar orbit at 833 km altitude with an ascending node crossing time of 2:30 PM. The HITS instrument was designed to spectrally resolve the 834 Å triplet to demonstrate a new technique for remotely sensing the electron density in the F-region ionosphere. In addition, the HITS was able to spectrally resolve the rotational structure of the N2 Lyman-Birge-Hopfield (LBH) bands, which was used to infer the thermospheric temperature. The HITS observed the Doppler shifted spectrum of proton recombination during proton aurorae, which was modeled to infer the energy distribution of the protons. The instrument operated as a limb imager with a limb scan occurring every 100 seconds throughout the ARGOS mission life, May 1999 – early April 2002. Its field-of-view was $0.06° \times 4.6°$, which corresponded to 3 km (altitude) $\times$ 230 km (along the horizon) at the limb. The instrument's field-of-regard was $17° \times 4.6°$, which covered the 100-750 km altitude range. We will present an overview of the instrument, discuss its calibration and in-flight performance, and present some of the observations and results.

4.c.4 16:15 - 16:30: Kenneth Dymond: The Ionospheric Spectroscopy And Atmospheric Chemistry (ISAAC) Experiment on the Advanced Research and Global Observing Satellite (ARGOS)

- Naval Research Laboratory

Co-author(s): Scott Budzien
- Naval Research Laboratory

The Ionospheric Spectroscopy And Atmospheric Chemistry (ISAAC) Experiment was a high resolution mid-ultraviolet Ebert-Fastie spectrograph that flew on the USAF Advanced Research and Global Observing Satellite (ARGOS, launched 23 February 1999). The ARGOS is in a sun-synchronous, near-polar orbit at 833 km altitude with an ascending node crossing time of 2:30 PM. The ISAAC instrument was designed to spectrally resolve the rotational structure of the nitric oxide bands, which was used to infer the temperature in the lower thermosphere (90-200 km altitude range). The instrument is operated as a limb imager with a limb scan occurring every 100 seconds throughout the mission life of the instrument, which began in mid-May 1999 and went through the infamous Bastille Day storm that occurred on July 14, 2000.

The ISAAC instrument was composed of a 1/8 m focal length Ebert-Fastie spectrograph with an intensified plasma coupled device (PCD) detector. The instrument used a 3600 l/mm diffraction grating. The ISAAC covered 400 Å overlapping segments of the 1800-3300 Å passband at better than 4 Å spectral resolution. A stepper motor drive with a 4 position cam assembly was used to tilt the grating and select the instantaneous passband. The spectrograph was fed by a 1/8 m focal length off-axis parabola telescope. Its field-of-view was $0.03° \times 1.1°$, which corresponded to 1.5 km (vertical) $\times$ 55 km (along the horizon) projected to the limb. We present an overview of the instrument, discuss its calibration and in-flight performance, and summarize some of the scientific results from the instrument.

4.c.5 16:30 - 16:45: Rick Doe: Narrowband Nanosatellite-Scale Photometry for VUV Aeronomy

- SRI International

Co-author(s): John Noto, Lara Waldrop, Harald Frey, Gary Bust
- Scientific Solutions Incorporated, University of Illinois, University of California - Berkeley, Johns Hopkins University APL

Remote vacuum ultraviolet (VUV) soundings to support Explorer-class atmospheric research are typically enabled by large aperture, wideband spectrographs carefully pointed to measure a planet's disk and limb regions (i.e. TIMED/GUVI and MAVEN/UVS).

An alternate measurement paradigm is to identify key aeronomical emission targets (i.e. HI 121.6-nm, OI 135.6-nm, N2 Lyman-Birge-Hopfield band 135 - 155 nm) and create a series of narrowband photometers each with greater in-band sensitivity (relative to a spectrograph) due to enhanced out-of-band rejection and absence of a dispersive element.

Recent advances in narrowband VUV coating and PMT miniaturization have enabled design of a dual-channel nanosatellite-scale VUV photometer with flight heritage significantly leveraged from the NASA POLAR UVI imager the Air Force CubeSat Tiny Ionospheric Photometer (CTIP).

Herein we discuss the modeled performance and build status of the dual-channel thermosphere/ionosphere photometer (DTIP) and address notional missions including dayside O/N2 composition, auroral energetics, nightside plasma structuring, and ionospheric peak layer characterization. We also present an imaging mode in which the VUV photometer is slowly rotated within the orbit plane to enable radiance measurements on multiple overlapping look directions - a geometry ideal for tomographic image reconstruction. Notional ionospheric and geocoronal missions invoking this tomographic scenario will be summarized.

4.c.6 16:45 - 17:00: Christoph Englert: MIGHTI: Interferometers for the observation of thermospheric neutral wind and temperature on board the ICON satellite mission

- Naval Research Laboratory

Co-author(s): John M. Harlander, Charles M. Brown, Jonathan J. Makela, Kenneth D. Marr, Thomas J. Immel
- St. Cloud State University, Naval Research Laboratory, University of Illinois, Praxis Inc., University of California - Berkeley

The Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) is one of the four instruments on the NASA Ionospheric Connection (ICON) Explorer mission, scheduled for launch in 2017. ICON will investigate the extreme variability of the Earth's ionosphere with a unique combination of sensors on-board a low Earth orbit satellite. The MIGHTI instrument will measure the global distribution of neutral winds and temperatures over an altitude range not accessible to *in-situ* probes. MIGHTI uses the Doppler Asymmetric Heterodyne Spectroscopy (DASH) technique for the wind measurements and a multi-color photometer technique to measure temperature. Here we discuss the overall instrument design and performance.

5 17:15 - 19:00: PARALLEL SESSIONS – Ground, Particles, Fields

5.a Ground – Radio 1 [North]

Chair(s): J. M. Ruohoniemi

5.a.1 15:15 - 15:35, *Invited*: Ivan Galkin: Global Monitoring of Bottomside Ionospheric Plasma with GIRO Sensors

- University of Massachusetts, Lowell

Co-author(s): Bodo Reinisch, Xueqin Huang
- Lowell Digisonde International

A "quiet revolution in sensor networks", as analysts called it in 2003, has played its enabling role in transforming the high-frequency (HF) ionosonde network incepted in 1955 into a near real-time, unattended, automatic, global-coverage space weather resource. Several technologies have been instrumental to this transformation. The Automatic Real-Time Ionogram Scaler with True height (ARTIST) software became standard on Digisonde® sounders in the early 1980s, followed by a suite of ionogram autoscaling tools for other ionosondes. Self-tested "glass-room" operations at remote observatories were put in practice in the 1990s. Open-access online databases holding ionogram-derived data, originally introduced for the Space Physics Interactive Data Resource (SPIDR) project at NOAA in the mid-1990s, started accepting real-time and raw ionogram data in 2002 to eventually become what is known today as the Digital Ionogram Database (DIDBase). Ultimately, these advances led to the "no time or distance barriers" status of the ionosonde network and establishment of the Global Ionosphere Radio Observatory (GIRO) in 2008. Taking advantage of the real-time availability of measured electron density profiles at 45+ GIRO locations, assimilative models could then provide continuous global ionospheric electron density nowcast and forecast. Among these models, a real-time extension of the International Reference Ionosphere (IRI), the IRI-based Real-Time Assimilative Model (IRTAM) became operational at the Lowell GIRO Data Center (LGDC) in 2013. The IRTAM employs a new robust technique of manipulating the internal constituents of the IRI maps of ionospheric characteristics into agreement with available measurements from GIRO. Historical records of the IRTAM-computed real-time maps of F2 layer peak height hmF2 and density NmF2 (or critical frequency foF2), originally provided as 24-hour latest map animations at `http://giro.uml.edu/IRTAM`, have been made publicly available for download and visualization via the Global Assimilative Model of Bottomside Ionosphere Timeline (GAMBIT) Database and Explorer software. Additionally, the GIRO science team focused on the capability of the Digisondes to measure the Doppler frequency shift and angle of arrival variations on received vertical and oblique echoes. This advanced capability has proven useful for detecting and characterizing traveling ionospheric disturbances, evaluating layer tilts in the ionosphere, and measuring the velocity of field-aligned plasma movements associated with artificial heating of the ionosphere. Further enhancements of GIRO services for research and applications are directed at expanding the list of contributing ionosondes, including non-Digisonde models as long as they provide ionogram autoscaling, and adding new databases and explorers to the LGDC open access roster.

5.a.2 15:35 - 15:55, *Invited*: Juha Vierinen: Small form factor ionosonde for ionospheric radio remote sensing

- MIT Haystack Observatory

Co-author(s): Frank D. Lind, Philip J. Erickson, Anthea J. Coster
- MIT Haystack Observatory

We give an update on recent progress to design a low cost, low power, and small form factor ionosonde. Ionosondes are radars operating across multiple frequencies in the HF band. Radar echoes from the bottom side of the ionosphere are used to deduce the plasma frequency and the electron density profile of the bottom side of the ionosphere. The key design feature of the our new ionosonde is that it transmits continuous coded low power pseudorandom noise. This is to reduce interference with other users of the HF band, but also to allow simultaneous sounding of the sounding with multiple such ionosondes at the same time, as each sounder can distinguished from each other by using unique pseudorandom waveforms on each sounder. We outline the principles of the signal processing involved, including how to receive multiple transmissions simultaneously. We show latest results from a prototype instrument that we have recently built and are using with an experimental license.

5.a.3 15:55 - 16:08: Cody Vaudrin: Multistatic Meteor Wind Radar and Results from a Recent Observation Campaign in Adelaide, Australia

- University of Colorado

Co-author(s): Scott Palo
- University of Colorado

The Colorado Software Radar (CoSRad) comprises a fully functional FPGA-based software-defined radar remote sensing transceiver. CoSRad is a software configurable data acquisition system designed to operate over a wide range of radar remote sensing topologies. Ultimately, CoSRad endeavors to deploy a worldwide network of radars based on a common hardware platform and non-proprietary data processing techniques. CoSRad uses a direct-convert architecture to continuously sample eight antenna feeds and extract signals of interest from the resulting data stream. A brief overview of the CoSRad hardware and software configured for multistatic specular meteor wind radar (MWR) mode is followed by results from a recent measurement campaign in Adelaide, Australia. A CoSRad-based multistatic MWR was deployed and used to observe the Geminids meteor shower that peaked on Dec 14th, 2014. A multistatic MWR is defined by two or more geographically distributed (over 100's of km) receiver stations as opposed to the traditional MWR where the transmitter and a single receiver are co-located. Multistatic MWR is different from the traditional multistatic meteor radar where closely spaced stations (10's of km) are used to observe scatter simultaneously from the same trail for meteor orbit determination purposes.

A brief overview of meteor trail scatter theory is followed by a series of example backscatter and forward-scatter echoes. A number of different visualizations are presented and interferometric direction-of-arrival techniques are discussed. Trail echo rates are presented between the forward and backscatter stations, and the inter-station echo rates are then compared with those expected from the trail scattering theory and assumed meteoric trajectory distributions associated with the Geminids meteor shower. The talk concludes with a discussion of how this measurement campaign has laid the foundation for multistatic MWR's potential to improve the mesospheric wind field estimate and provide new experimental insight into meteor trail scattering and trail diffusion processes.

5.a.4 16:08 - 16:21: Stephen Kaeppler: Ionospheric Imaging Using Incoherent Scatter Radar and Ground-Based Optical Imagers

- SRI International

Co-author(s): Michael Nicolls[1], Russell Cosgrove[1], Anja Stromme[1], Don Hampton[2]
- [1]SRI International, [2]University of Alaska - Fairbanks

Recent advances in incoherent scatter radar (ISR) technology and techniques have enabled observations of the high-latitude ionosphere in multiple spatial dimensions. Advanced Modular Incoherent Scatter Radar (AMISR) systems are capable of beam steering on a pulse-to-pulse cadence that enable nearly simultaneous sampling of extended structures in the meridional and zonal dimension. A new circular scan mode near has been developed at the Sondrestrom Radar facility to sample off magnetic zenith in a localized 3-D volume. Both of these modes enable sampling over a larger spatial region than has previously been possible and especially in the zonal dimension. These imaging modes enable 3-D estimates of the ionospheric electron density and 2-D estimates of the plasma velocity field [Nicolls et al., 2014, Heinselman and Nicolls, 2008]. We present a brief review of these techniques. A next step forward in ISR imaging is to fold in complimentary, co-located, data sources that can be used with the ISR data to improve estimates of ionospheric parameters. All-sky color imagers, co-located with ISRs, make line-of-sight measurements of the visible light emission at a variety of different wavelengths corresponding to different physical processes. The all sky imagers generally provide measurements over a larger field-of-view and at much higher time cadence than ISR, thus the measurements contain useful information that can be used to enhance the spatial and temporal resolution of the 3-D electron density estimation. We present a new technique for merging photometric and ISR observations to generate improved estimates of the 3-D electron density structure in the auroral ionosphere. We present results from a recent study that validates the use of a forward electron transport model in combination with all-sky imagers and neutral temperature measurements.

5.a.5 16:21 - 16:34: John Swoboda: Three-dimensional ionospheric reconstruction using electronically steerable ISR

- Boston University

Co-author(s): Joshua Semeter, Philip Erickson
- Boston University, MIT Haystack Observatory

Electronically steerable array (ESA) technology has recently been applied to incoherent scatter radar (ISR) systems. These arrays allow for pulse-to-pulse steering of the antenna beam to collect data in a three dimensional region. This is in direct contrast to dish based antennas, where ISR acquisition is limited at any one time to observations in a two dimensional slice. This new paradigm allows for more flexibility in the measurement of ionospheric plasma parameters.

Multiple ESA based ISR systems operate currently in the high latitude region where the ionosphere is highly variable in both space and time. Because of the highly dynamic nature of the ionosphere in this region, it is important to differentiate between measurement induced artifacts and the true behavior of the plasma. Often three dimensional ISR data produced by ESA techniques are fitted in a spherical coordinate space and then the parameters are interpolated to a Cartesian grid, introducing potential error and impacting the reconstructions of the plasma parameters.

Previously the idea of a full space-time ambiguity function was introduced. This frame work poses the estimate of the of the time domain lags of the intrinsic plasma autocorrelation function as a linear inverse problem with the space-time ambiguity function as a blurring kernel over space and time.

Using this frame work we will reconstruct the plasma parameters using time domain lags which we will estimate using linear inverse theory. After which we will fit these lags to autocorrelation functions to determine the plasma parameters. We apply these technique to simulated ISR data in three dimensions created from plasma parameters that are non-homogeneous in space and time. These test cases will be created to mimic high latitude ionospheric phenomena such as auroral arcs and/or polar cap patches.

5.a.6 16:34 - 16:47: Philip Erickson: Next Generation Incoherent Scatter Radar: Science and Technology

- MIT Haystack Observatory

Co-author(s): F. D. Lind, J. Vierinen, R. Volz
- MIT Haystack Observatory

Incoherent scatter radar (ISR) has been used since the late 1950s to provide the most powerful available ground based probe of the Geospace environment. Using radar systems of sufficient power aperture product, and appropriate design, it is possible to remotely sense scatter from the ionospheric thermal plasma and derive physical quantities from these observations. The incoherent scattering technique provides the only direct detection of the full altitude dependence of plasma temperature along with electron density and ion composition, and other thermospheric parameters such as neutral winds and exospheric temperature can also be sensed indirectly. In some cases ion compositional information can also be derived, and recent systems have begun to provide volume imaging capabilities.

The observations of IS radar systems are spatially resolved and have had remarkable persistence, with multiple existing radar systems operating for 50+ years. The precise and well developed observations produced by this class of radars has formed the backbone of community knowledge about ionospheric plasma and its variations. Data from existing systems has also been combined with complementary observations from other instrumentation (e.g. satellites, GPS TEC, HF radar, etc). ISR has developed technologically and theoretically in the last decade, and this has provided notable improvements in the capability and flexibility of existing instruments. These developments have largely been driven by recent advances in computing technology. Examples include software defined radios, software radar architectures, perfect radar coding techniques, and advanced signal processing and inversion methods. These developments have set the stage for new observational paradigms that are highly flexible, volumetric, persistent, and that employ incoherent scatter radar jointly with other radio science techniques (e.g. radio telescopes).

New instrumentation classes are now possible including advanced low cost digital array radars, deployable and reconfigurable radio imaging arrays, and hybrid systems which explicitly combine active and passive radio imaging techniques. Such systems enable a persistent and uniform view of the ionosphere over a wide simultaneous altitude range along with a wide range of other scientific applications. Radar systems and, by extension, networks of radars are able to optimize measurements by adapting dynamically to changing geophysical conditions. Initial efforts to develop such instrumentation have provided glimpses of what will be possible in the future. We will present examples from these early development efforts, describe the design of an incoherent scatter radar architecture which can take advantage of these capabilities, and discuss concepts of how the next generation of incoherent scatter radar systems can provide new and unique insights into geospace phenomena.

5.a.7 16:47 - 17:00: J Michael Ruohoniemi: Advances in ground-based observations of the magnetosphere, ionosphere, and upper atmosphere with the SuperDARN HF radar technique

- Virginia Tech

Co-author(s): Joseph Baker, Simon Shepherd, William Bristow, Ethan Miller
- Virginia Tech, Dartmouth College, University of Alaska
- Fairbanks, Johns Hopkins University APL

Remote sensing of the ionosphere with radars has been a mainstay of research in space physics. The technique of incoherent scatter is powerful in providing a comprehensive set of plasma diagnostic measurements but its application is limited by relatively high costs of construction and operation. The technique of coherent scatter is capable of providing a more limited set of measurements at modest cost so that it becomes possible to envision the creation of extensive networks of radars that provide large-scale coverage with continuous operation. The most complete realization of this concept is the Super Dual Auroral Radar Network (SuperDARN) which now consists of over thirty radars operating as chains distributed at polar, high, and mid latitudes in both hemispheres. The SuperDARN measurements of plasma drift velocity are widely applied and are well-known as the basis for producing maps of the global convection pattern on the 1 or 2 minute cadence of the radar scanning. The recent construction of a chain of radars at mid-latitudes in the North American sector has provided new views of the subauroral ionosphere and of storm-time processes such as subauroral polarization streams and their dramatic effects on plasma redistribution. More radars are either planned or under construction by the SuperDARN partners. When combined with other large-scale methods of imaging ionospheric effects such as TEC and field-aligned currents we approach a system-level capability for depicting M-I processes and testing and developing space physics models. Comparison with incoherent scatter radar measurements makes it possible to resolve basic plasma physics of the ionosphere including the causes of plasma instability. Another emergent area for research is the exploitation of the basic HF backscatter measurement itself to provide diagnostic measurements of the ionosphere of particular importance for space weather such as the distribution bottomside F region plasma density and the occurrence of irregularities and the potential for GPS scintillations. We will review the recent advances and anticipate the next steps towards realizing the full capabilities of the HF coherent backscatter technique.

5.b Particles – Neutral Gas [Center]

Chair(s): D. Delcourt

5.b.1 17:15 - 17:35, *Invited*: Gregory Earle: Neutral Pressure and Wind Measurement Technologies to Address Thermospheric Science Objectives

- Virginia Tech

Co-author(s): Cameron Orr[1], Vidur Garg[1], Peter Marquis[1], Stephen Noel[1], Grant Roth[1], Ryan Davidson[2], J.-B. Lee[3], Jun-Hyeon Yoo[3], Ted Beach[3], Odile Clavier[4], Christopher Holland[5]
- [1] Virginia Tech, [2] Utah State University, [3] UT Dallas, [4] Creare LLC, [5] SRI International

Accurate measurements of neutral winds and pressure are extraordinarily difficult to make from orbital spacecraft, but they are state variables that have profound effects on the dynamics and stability of the thermosphere and the ionosphere. The technical challenges associated with such measurements are exacerbated by the high cost of spaceflight missions, which is reducing the frequency of the Explorer and Discovery class missions that have historically produced the most comprehensive data sets. In this paper we present a few examples of neutral wind and pressure observations from instrumentation that flew for the first time aboard the C/NOFS satellite. We then describe several ongoing projects in which low-resource technologies are being developed and tested to establish their feasibility for smaller, lower-power instrumentation. These low resource designs include CubeSat adaptations of the C/NOFS instruments, plus new approaches to ionization sources and capacitance manometers that have the potential to significantly reduce the size, weight, and power (SWaP) of satellite-borne neutral wind and pressure instrumentation. Design and laboratory test data will be shown to demonstrate the feasibility of the new approaches. Some of these new techniques may eventually supplant current technologies, thereby making future *in-situ* wind and pressure instruments smaller and more affordable. If successful, these efforts may ultimately enable high-fidelity wind and pressure measurements to be made from smaller, less expensive satellite platforms, which are the most likely candidates for future satellite constellation missions.

5.b.2 17:35 - 17:55, *Invited*: James Clemmons: Techniques and instrumentation for *in-situ* measurements of the upper atmosphere

- The Aerospace Corporation

Techniques and instrumentation for *in-situ* measurements of upper atmospheric parameters are presented and discussed. The focus is on the employment of sensitive pressure gauges, and various aspects of the techniques applied and instrumentation utilized are highlighted. Issues with these methods are presented, and their mitigations described and discussed using illustrative examples from recent measurements. A roadmap toward greater capabilities is put forth, and current and future technique and instrumentation developments are described.

5.b.3 17:55 - 18:08: Stefano Livi: Strofio: A Novel Neutral Mass Spectrograph for Sampling Mercury's Exosphere

- Southwest Research Institute

Co-author(s): Mark Phillips[1], Mihir Desai[1], Frederic Allegrini[1], George Ho[2], Reid Gurnee[2], Peter Wurz[3], Jurgen Scheer[3]
- [1] Southwest Research Institute, [2] Johns Hopkins University APL, [3] University of Bern

Strofio is a scientific investigation to sample *in-situ* the neutral atoms in Mercury's exosphere. Strofio is based on a novel mass spectrograph that determines the particle mass-per-charge (m/q) by a time-of-flight (TOF) technique. This novel technique achieves a mass resolution (m/Δm) at mass 18 of >100, with a high sensitivity of 0.14 (counts/s)/(particles/cm^3) and a mass of only 4kg. Strofio employs a rotating electric field to "stamp" the start time of the incoming ionized particles and a micro-channel plate (MCP) detector to record the stop time and position. This eliminates the need for foils or shutters, resulting in nearly 100% duty cycle and a low mass design. Strofio is funded by NASA to fly on the European Space Agency mission Bepi-Colombo to the planet Mercury. It is part of the four instrument SERENA suite situated on the Mercury Planetary Orbiter (MPO), which will enter in a 400 × 1500km polar orbit.

5.b.4 18:08 - 18:21: Andrew Nicholas: RAMS: A Miniature Ram Angle and Magnetic Field Sensor

- Naval Research Lab

Co-author(s): Federico Herrero[1], Glenn Creamer[2], Theodore Finne[2], Ivan Galysh[2], James Armstrong[2]

- [1]Space Systems Research Corporation, [2]Naval Research Lab

The popular and well-established concepts for satellite attitude sensing, including Earth horizon sensing, Sun sensing, geomagnetic field sensing, and star sensing have had almost no new revolutionary additions in decades. In this paper we introduce a new attitude sensing concept and prototype miniature sensor called RAMS (Ram Angle and Magnetic field Sensor). This novel instrument directly measures the *in-situ* 2-axis ram direction of a LEO satellite by collecting the incoming thermospheric flow field through a wide field of view entrance aperture, ionizing the neutral molecules in a thermionic cathode chamber, adjusting the kinetic energy of the charged molecules in an electric field, and measuring their impingement location in two coordinate axes on a quad detector. Coupled with its own built-in magnetometer, RAMS provides an estimate of the satellite's 3-axis attitude relative to the local orbit frame regardless of roll angle or sunlight conditions as long as the ram direction is within the field of regard of the entrance aperture. If available, an external Sun sensor can be utilized in place of the magnetometer during daylight conditions. As a by-product of interest to the space weather community, the sensor also provides a measure of the *in-situ* cross track winds and density of the thermospheric neutrals.

The RAMS sensor head has a mass of 23 g, occupies a volume of 22.5 cubic cm, and an expected power draw of ∼0.5 W. The measurements consist of the two angles (α, β) defining the projection of the ram vector R relative to the x-axis of the sensor frame, and the components (Bx, By, Bz) of the local geomagnetic field vector B from the built-in magnetometer. The ram velocity is the vector sum of the satellite velocity vector V and the total wind vector W, our measurement accounts for the vector sum of V and the component of W perpendicular to V. We will describe in detail the sensor components and software modules necessary for estimating the horizontal wind angle and the satellite attitude from the instrument measurements. Additionally, we will provide both high-fidelity simulations and ground calibration from a flight RAMS unit highlighting its potential for sub-degree attitude estimation in a light-weight, low-volume, low-power, and low-cost package compatible with the extreme limitations of CubeSat-class missions.

5.b.5 18:21 - 18:34: Steven Watchorn: Development of the Nanosat O2 A-band Spatial Heterodyne Interferometer (NOASHIN)

- Scientific Solutions, Inc.

Co-author(s): John Noto, Richard Doe, Chad Fish

- Scientific Solutiuons, Inc., SRI International, ASTRA

The abundance of CO2 in the mesopause region has long been shown to track with mesopause cooling, making mesopause-region temperature measurement a way to track CO2 abundance in this critical region, where climate change indications often manifest early. One of the brightest thermally excited emissions in the mesopause region is the O2 A-band, whose emission peaks are significantly modulated as a function of temperature. Thus, spectroscopic recovery of a set of A-band emission lines between 763 and 765 nm, and a comparison of peak intensities, will provide information about mesopause temperature, and thus CO2 abundance. To get global coverage of this emission with high time resolution ($<$ 1s) requires a high-etendue spectrometer that can resolve the target lines (resolution ∼ .06 nm), preferably aboard an efficient, economical vehicle capable of the global coverage that would be most beneficial to existing mesopause models. Nanosatellites are such a vehicle.

The NOASHIN instrument is a spectrometer very well suited to the low size, weight, and power (SWAP) of the nanosat platform. It is built around a Spatial Heterodyne Spectrometer (SHS), a monolithic Fourier transform spectrometer with no moving parts that shares the high etendue, high resolution advantages of conventional interferometers in a robust package ideal for space-based platforms. The NOASHIN instrument will be developed for, ultimately, a 1-U CubeSat, nadir-viewing nightglow measurement payload, used in a pushbroom imaging configuration from low-Earth orbit ($\sim$ 650 km), with an exposure time of < 1 s, leading to a target footprint of 9-km along-track.

The current development project will integrate a prototype NOASHIN SHS monolith into a 1.5-U CubeSat engineering prototype at the design SWAP requirements. The prototype will be detect emissions of the expected intensity ($\sim$700 R) from a lab source near the A-band and offload data onto a local computer for analysis.

5.b.6 18:34 - 18:47: Xinzhao Chu: Geospace and Atmosphere Observatory at Arrival Heights for Studies of Space-Atmosphere Interaction Region with Optical and Radio Remote Sensing in Antarctica

- University of Colorado - Boulder

Co-author(s): Chester Gardner, Allan Weatherwax

- University of Illinois, Siena College

Polar atmosphere and geospace environment provides one of the best opportunities to advance our understanding of the fundamental universal processes in the Earth's space-atmosphere interaction region (SAIR) and how they shape the atmosphere of Earth-like planets throughout our galaxy. Many coupled feedback processes are at play in a planetary atmosphere system. But many are unknown and cannot be addressed without a complete description of the atmosphere, from its lower interaction with land and oceans to its upper interaction with space. The natural upward extension of a planet's atmosphere ultimately leads to its interaction with space, where atmospheric neutral gasses become entwined with the dynamic plasma of space. This SAIR is common to all planetary systems, yet its properties, and the processes that govern them, are not sufficiently described to fully understand its role in an atmosphere's development and evolution. SAIR is known to be essential for sustaining life on Earth by absorbing extreme solar radiation, ablating meteoric material, regulating gaseous escape, dissipating energetic particles and fields from space, while balancing influences from the planet itself in the form of wave energy and momentum originating from the lower atmosphere.

One of the best sites on Earth to study SAIR with ground-based instruments is the Arrival Heights Observatory (77.8S, 166.7E) near McMurdo, Antarctica. Numerous optical and radio remote sensing instruments (e.g., lidar, imager, photometer, radiometer, magnetometer, ELF/VLF, GPS, etc.) have been developed and deployed at this site, forming an observational cluster for multi-dimensional investigation of polar geospace. Furthermore, several new discoveries at Arrival Heights have intrigued new interests in the solar and space physics. Thermospheric neutral Fe layers up to 170 km, discovered recently by Fe Boltzmann lidar observations at Arrival Heights, have opened a new door to observing the neutral polar thermosphere with ground-based instruments. These metal layers provide tracers for resonance lidars to directly measure the neutral temperatures and winds in the thermosphere. Indeed, neutral temperature measurements have been demonstrated from 30 to $\sim$170 km at Arrival Heights. This measurement extension has opened a new interest in polar ionosphere-thermosphere-magnetosphere coupling, as Fe^{+}, when neutralized, can now be directly measured.

New observational capabilities needed to make Arrival Heights a world-class geospace observatory will be discussed. Two major new instruments include a new Doppler lidar and incoherent scatter radar (ISR). Complementing the current Boltzmann lidar, the new Doppler lidar allows for the studies of, among others, meteoric/cosmic dust influx, gravity and tidal waves, and atmospheric circulation. With the high-resolution and large-range neutral winds, especially vertical wind capabilities, new frontier sciences will be enabled at Arrival Heights. ISR technology has long represented an effective ground-based monitoring capability in the upper atmosphere and ionosphere. Arrival Heights Observatory is important for continued progress in understanding the Sun's influence on the structure and dynamics of the ionosphere and thermosphere and coupling to the lower atmosphere. These questions are especially relevant today as rising concentrations of greenhouse gases are changing Earth's climate and increasing numbers of extra-solar planets are being discovered in our galaxy.

5.b.7 18:47 - 19:00: Marcin Pilinski: A Neutral Gas Concentrator on the Mass Analyzer for Real-time Investigation of Neutrals at Europa

- ASTRA LLC.

Co-author(s): Murray Darrach[1], Stojan Madzunkov[1], Tim Minton[2]

- [1] *NASA JPL,* [2] *Montana State University*

The utility of spaceborne mass-spectrometers flying in low-density atmospheres can often be limited by instrument sensitivity and long response times. These challenges can prevent such instruments from addressing certain science questions while fitting within a compact volume. Solutions to these problems are needed for the *in-situ* sensing of planetary upper thermospheres as well as in the tenuous exospheres of icy bodies. The JPL-built Mass Analyzer for Real-time investigation of Neutrals at Europa (MARINE) addresses these issues by combining a sensitive detector with a novel instrument inlet. The focus of this presentation will be the design and anticipated performance of the inlet system. An overview of the MARINE instrument components will also be presented.

The inlet system of a typical closed-source mass-spectrometer serves to accommodate the incoming neutral gas to some known temperature and to increase the signal gain by increasing the "ram" pressure. The former is accomplished by ensuring that incoming molecules undergo many (>100) reflections with the inlet surfaces wherein each successive collision causes the molecule to lose some of its original energy and thus become accommodated to the surface temperature. Increased gain is achieved by allowing "ram" pressure to build up inside the inlet increasing number densities in the ion-source relative to number densities in the free-stream. A consequence of these design features is that molecules must necessarily be "slowed" inside the inlet by the many reflections they undergo on their way to the ion source. This increase in transmission-time can cause delays in the time-response of the instrument, distorting the signal. The experience from the Cassini-INMS has shown that transmission times for non-volatile species through the inlet can be as much as 150 seconds.

In order to achieve the signal levels desired for analysis of Europa's tenuous atmosphere and to map those signals to sources on the surface, an inlet system is required that has higher gain as well as faster response times than previous designs. We have evaluated an inlet composed of various molecular-concentrator designs using a numerical test-particle code called the Statistical Program for Aerodynamic and Radiation Coefficient Simulation (SPARCS). Sensitivity and trade studies using the SPARCS program were performed on several designs. We investigated the performance of concentrator geometries using gas-surface interaction parameters measured in the laboratory as well as those inferred from spaceflight experiments. The hypersonic beam laboratory-testing is being performed at a facility on the Montana State University campus and is being led by Dr. Tim Minton.

In this presentation, we will review the instrument and inlet requirements, summarize the MARINE design, and provide a summary of analyses for a variety of concentrator geometries. Next we show results of modeled MARINE measurements in the atmosphere of an icy moon. The measurement-model results are shown for a MARINE instrument equipped with a concentrator and compared to the performance of an instrument having only an accommodation chamber. Finally, we review preliminary surface-scattering test results made using a hypersonic atomic oxygen beam and a sample of the concentrator material.

5.c Fields – DC Magnetic Fields [South]

Chair(s): N Murphy, H. Korth

5.c.1 17:15 - 17:35, *Invited*: Neil Murphy: Techniques for absolute measurement of magnetic fields from spacecraft

- *NASA JPL*

While space-based instruments that measure the three components of the magnetic field vector provide the necessary sensitivity for most measurement applications, a subset of missions require the additional accuracy afforded by an absolute measurement of the field. Such measurements are termed absolute as their measurements can be related to known constants, and thus require minimal calibration, and their accuracies can be as high as 1 part in 100,000. Such accuracies allow, for example, the determination of small secular changes in planetary fields, or can be used to continuously calibrate vector instruments. We will discuss the range of techniques used to make absolute field measurements, and also recent developments in compact scalar and combined vector-scalar instruments

5.c.2 17:35 - 17:50: Haje Korth: Miniature absolute scalar magnetometer based on the rubidium isotope 87Rb

- *Johns Hopkins University APL*

Co-author(s): Kim Strohbehn[1], John Kitching[2], S.Knappe[2]

- [1] *Johns Hopkins University APL,* [2] *National Institute of Standards and Technology*

The magnetic field is a fundamental physical quantity, and its precise measurement plays a central role in addressing the scientific objectives of many planetary, solar, and interplanetary science missions. Ultra-precise measurements are made by atomic magnetometers based on absolute frequency standards. However, a major disadvantage of these instruments is their significant mass and high power requirements, which effectively prevent their routine use in space. Hence, to allow for more widespread use of atomic magnetometers in space, mass, size, and power consumption of these instruments must be substantially reduced. In response to an on-going paradigm shift in space research, we have developed a low-resource, miniaturized, absolute scalar magnetometer based on the rubidium isotope 87Rb. Our instrument takes advantage of recent breakthroughs in micro-fabricated atomic devices, which have demonstrated reductions of power requirements and mass by one to two orders of magnitude over conventional instruments. Our device employs a low-power semiconductor laser and a miniature rubidium vapor cell of millimeter dimensions produced using modern micro-fabrication processes. The combination of microelectromechanical systems (MEMS) vapor cell and a semiconductor diode laser has allowed a substantial reduction in mass, size, and power dissipation of atomic magnetometers with only modest decrease in performance. An additional key aspect in the miniaturization of the device is the monolithic integration of the vapor cell with heaters and Helmholtz coils using silicon-on-sapphire (SOS-CMOS) technology. The heater is implemented using multiple magnetic-field compensating loops in neighboring layers of the chip to yield near-perfect annihilation of contamination magnetic fields in close vicinity of the detection volume. The chip also generates the radio-frequency magnetic field necessary to establish the atomic resonance via two single-turn circular coils in Helmholtz configuration. The sensor is controlled by electronics and software in an FPGA, which generates the signals to excite the rubidium atoms within the vapor cell and measures and processes the resonant response at a rate of 10 samples per second. The resulting instrument has a total mass of less than 500 g and uses 0.5 W of power, while maintaining sensitivity, 15 pT/$\sqrt{}$Hz at 1 Hz or about 0.1 nT rms, comparable to present state-of-the-art absolute magnetometers. The prototype instrument demonstrates that absolute magnetometers can be miniaturized to serve future planetary missions even under severe resource constraints.

5.c.3 17:50 - 18:05: Andreas Pollinger: Key parameters of the Coupled Dark State Magnetometer

- *Space Research Institute / Austrian Academy of Sciences*

Co-author(s): Werner Magnes[1], Roland Lammegger[2], Michaela Ellmeier[2], Christian Hagen[1], Irmgard Jernej[1], Wolfgang Baumjohann[1]
- [1]*Space Research Institute / Austrian Academy of Sciences,* [2]*Institute of Experimental Physics / Graz University of Technology*

The Coupled Dark State Magnetometer (CDSM) is a scalar magnetometer based on two-photon spectroscopy of free alkali atoms. A quantum interference effect called Coherent Population Trapping (CPT) leads to narrow optical resonance features, which enable a precise determination of the magnetic field dependent Zeeman energy level shifts. Systematic errors which usually degrade the accuracy of single CPT magnetometers are cancelled or at least minimized by the use of several CPT resonances in parallel. Thus far CPT is the only known effect used in optical magnetometry which inherently enables omnidirectional measurements. This leads to a moderately complex, all-optical sensor design without double cell units, excitation coils or electro-mechanical parts.

A prototype was developed as an Engineering Model for the China Seimo-Electromagnetism Satellite (CSES) mission. The Flight Model will be launched into a low Earth orbit at the end of 2016. It will be the first demonstration of this new measurement principle in space. Furthermore, the CDSM is a baseline instrument for the JUpiter ICy Moon Explorer (JUICE) mission of the European Space Agency (ESA) to visit the Jovian system. The selection process required an uplift of the Technology Readiness Level (TRL) to five. With a currently scheduled launch in 2022, the JUICE mission will focus on the study of Jupiter's Galilean moons Ganymede, Callisto, and Europa. Despite the development towards an instrument for scientific space missions, the CDSM is also seen as candidate for ground-based applications, e.g. measurements in geomagnetic observatories. The Engineering Model for the CSES mission has a mass of 866 g and the power consumption is 2167 mW. The sensitivity of 20 to 50 pT/$\sqrt{}$Hz at 1 Hz does not depend on the selectable instrument bandwidth. The dynamic range spans from demonstrated 25 nT up to extrapolated 1 mT with identical performance.

The presentation includes an introduction on the measurement principle, the instrument design for the CSES mission, possible improvements for the JUICE mission and performance characteristics such as accuracy, noise and sensor heading dependence.

5.c.4 18:05 - 18:20: David Miles: Towards a Next Generation Fluxgate Magnetometer

- University of Alberta

Co-author(s): David Baron[1], John Bennest[2], Andy Kale[1], Ian Man[1], David Milling[1], Barry Narod[3], Donald Wallis[4]

- [1]University of Alberta, [2]Bennest Enterprises Ltd., [3]Narod Geophysics Ltd., [4]Magnametrics

Fluxgate magnetometers are an essential tool for solar-terrestrial research including monitoring and forecasting space weather. Fluxgates provide high precision measurements of the Earth's magnetic fields, can infer the currents which transport mass and energy through the magnetosphere and ionosphere, and are generally required to interpret charged particle measurements. This talk highlights recent advances in fluxgate measurement technology undertaken at the University of Alberta in Canada and some recent instrument designs. A prototype instrument, with a 100 krad manufacturing path, was developed which combined direct digitisation of the sensor, digital feedback from two cascaded pulse-width-modulators combined with analog temperature compensation. These changes increase the measurement bandwidth up to 450 Hz with the potential to extend to at least 1500 Hz. The instrument can resolve 8 pT on a 65,000 nT field with a magnetic noise of less than 10 pT/$\sqrt{\text{Hz}}$ at 1 Hz. This performance is comparable with other recent digital fluxgates for space applications most of which use some form of sigma-delta modulation for feedback and omit analog temperature compensation. This design is being generalised for use as a replacement for Canada's nationwide CARISMA magnetometer array. A modified version will fly on the Norwegian ICI-4 sounding rocket in February 2015, and a miniaturised version is being developed for the ExAlta-1 cube-satellite. These flights will be used as qualification tests for a future space flight DC magnetometer for exploration of the terrestrial and planetary magnetospheres and the heliosphere.

5.c.5 18:20 - 18:35: Barry Narod: Advances in Permalloy cores for fluxgate magnetometers

- Narod Geophysics Ltd & University of British Columbia

Co-author(s): Paul Riley, Marc Lessard

- University of New Hampshire

Fluxgate magnetometers have been the mainstay instruments used for measuring magnetic fields in space and on the ground for decades, largely because of their simple design, relatively low mass and power requirements, as well as their radiation tolerance. These instruments have provided perhaps the most fundamental measurements of the space environment, measurements that have been used in thousands of publications. Still, improvements in lowering the internal noise levels of these sensors promises to open up new horizons for these instruments. Specifically, material improvements that seek to reduce noise associated with magnetic domain structure appear to be a promising approach. In fact, recent developments of first principles understanding of magnetic domain behavior in crystalline Permalloys has enabled the development of noise and hysteresis models for the Permalloy foils used in high performance fluxgate magnetometers. These in turn can be used to guide the development of new magnetic materials that can outperform materials currently in use. In particular they can be expected to be able to replace and outperform the 6-81 permalloy, Infinetics S-1000 ring cores which were produced and sold from before 1981 through to April 19 1996. As the existing inventory of the Infinetics ring cores finally vanishes the need for a replacement is clear. The models predict five property changes that should lead to performance improvements. These are: thicker foils; racetrack geometry; coarser grain structure; lower Bsat; longer track length. Using our own 6-81 material and only the first two property changes we have already created a core that outperforms Infinetics rings by 7 dB. Grain growth experiments currently underway may yield another 10 dB. New low Bsat alloys potentially can yield an additional 10 dB. Sub picoTesla fluxgate sensors are in principle possible with no power or size penalty.

5.c.6 18:35 - 18:55, *Invited*: Brian Anderson: Approaches to Spacecraft Magnetics Cleanliness in Support of Space Magnetic Field Measurements

- Johns Hopkins University APL

Whenever measurements of magnetic fields are made in space, the contributions of the spacecraft to the magnetic field at the relevant sensors must be considered. The approaches to spacecraft magnetics control and/or characterization vary greatly depending on the priority of the magnetic field measurements for the project objectives and on the requirements for magnetic field accuracy and frequency coverage. Venus Express and NEAR-Shoemaker employed minimal magnetics control and relied almost exclusively on post-launch characterization and data processing to discriminate against vehicle magnetic fields. By contrast, the science requirements for missions such as ACE, Cluster, MESSENGER, and MMS required very low magnetics contamination levels. When the magnetic field observations are central to the primary project objectives, booms are typically used to separate the magnetometer(s) at from the spacecraft to reduce spurious fields both constant and variable. In any case, but particularly when booms are not practical, care must be exercised in placement of the magnetometer sensors to be as removed as possible from sources of contamination fields. Focus is often given to subsystems with permanent magnets and those carrying the largest currents, typically the propulsion and power systems, respectively. Precise pre-flight assessment of the spacecraft permanent moment is often prohibitive for cost or accommodation reasons, so that determination of the fixed spacecraft field is often deferred until after launch and requires various techniques, depending on the mission target, using comparison with model fields or employing the characteristics of the ambient natural magnetic fields of the interplanetary medium. Time variable contamination fields can be particularly difficult or impossible to remove in post-processing and are best mitigated by design and verified during development. The magnetics control for the MMS mission was particularly challenging owing to the complexity of the four spacecraft and the number of sub-system elements provided by a large number of vendors and mission partners and this effort is used to illustrate a number of key elements in spacecraft magnetics efforts. To facilitate meeting the tight magnetics requirements for MMS, novel approaches to magnetics allocations and design guidance were used that allowed the engineering teams to target their designs and identify prominent magnetic sources early in the design phase of the project. In addition, testing through development required a consistent but simple measurement test plan that could be implemented by multiple engineering groups. By focusing attention on ensuring compliance with allocations rather than quantitative assessment of magnetic moments and emissions, the MMS project was able to implement a thorough yet cost-effective magnetics design and mitigation program.

18:55 - 19:00: Discussion

Tuesday, April 21, 8:30 - 19:00

6 8:30 - 10:15: PLENARY – Particles (#1) [Auditorium]

Chair(s): E. MacDonald, S. Jones

6.1 8:30 - 9:05, *Invited*: Thomas H. Zurbuchen: Innovations in Plasma Analyzers

- *University of Michigan*

Co-author(s): Dan J. Gershman
- *NASA GSFC*

Three basic drivers have motivated scientific and technological innovation in plasma analyzers. First, new science questions in a diverse set of space environments require higher fidelity plasma measurements, pushing the envelope of the status quo. Second, resource and operational constraints placed on plasma analyzers by increasingly complex and ambitious mission concepts have motivated new designs and analysis techniques. Finally, new technological breakthroughs have led to novel designs and fundamentally improved sensor performance.

Our presentation will provide a survey of plasma instruments since 1998, when Measurement Techniques in Space Plasmas: Particles was published. We will focus on examples in each of the three innovation drivers provided above and demonstrate how they have resulted in new designs and unprecedented datasets.

We will also provide an outlook of modern science questions that will likely drive the next generation of plasma sensors, discuss the key constraints placed on the increasing number of small missions and those employing multipoint measurements, and finally summarize technology frontiers that will most likely fuel plasma sensor innovation during the next decades.

6.2 9:05 - 9:40, *Invited*: James McFadden: Technology Challenges for Space Plasma Measurements

- *University of California - Berkeley*

Over the decades space plasma instruments have evolved to accommodate greater demands for science return. In conjunction with improvements in both electronics and particle detection, plasma analyzers have been developed to cover larger ranges in flux, energy and field-of-view, to provide better mass and time resolution, and to be more compact and therefore require fewer resources. The early qualitative measurements of the plasma environment have given way to quantitative measurements, where detecting small differences in plasma parameters are needed in order to understand the underlying physics. Identifying systematic errors, removing background, and determining absolute and relative calibration are all challenging aspects of current instrument design. Maintaining the ability to perform quantitative measurements over periods of years, in radiation environments where instrument degradation occurs, requires rigorous methods of inflight calibration. Multi-spacecraft missions, and satellites with multiple overlapping sensors, demand rigorous cross-calibration of different sensors in order to combine data sets. As spacecraft resources are squeezed, while science requirements are increased, scientists are pressed to develop new and better techniques for each mission. Unfortunately nature limits our ability to continually build smaller instruments with higher accuracy and faster time resolution since phase space can't be squeezed. So generally there are limits to reducing sensor resources without some new breakthrough technology. However, even without breakthrough technology there is still much room for improvement in terms of designing sensors that can provide more accurate measurements. This talk will take a look at the technology improvements of the past decade, including lessons learned about what did and did not work. In particular this talk will attempt to provide an overview of sensor dynamic range, time-of-flight mass composition techniques, measurement techniques for cold plasma, inflight and cross calibrations, background rejection and removal, instrument degradation, moment calculations, spacecraft charging, and error analysis.

6.3 9:40 - 10:15, *Invited*: Herbert Funsten: Particle Measurements in Challenging Environments

- *Los Alamos National Laboratory*

Our quest to understand the space environments of the interstellar medium, the Sun, and planetary bodies has driven us toward discovering fundamentally new signatures that illuminate the underlying physical processes that drive system structure and dynamics. These signatures may be dim, embedded in high backgrounds, and scale broad spectral, spatial, and temporal scales; furthermore, the observational platforms may traverse broad diversity of signature and background conditions. Innovative technologies and observational strategies have enabled understanding of increasingly complex signatures as well as discovery of fundamentally new signatures. Here, we review the status and direction of innovative technologies and methods of dim plasma signatures while embedded in substantial backgrounds. Of particular interest are the methods common to both *in situ* plasma measurements and remote sensing of distant plasmas through energetic neutral atom (ENA) imaging.

7 10:30 - 12:15: PLENARY – Ground (#1) [Auditorium]

Chair(s): P. Erickson

7.1 10:30 - 11:15, *Invited*: Eric Donovan: Ground-Based Geospace Observations - Taking it to the Next Level

- University of Calgary

Geospace is vast. Space/time scales that are relevant to its system-level dynamics span more than six orders of magnitude. The geospace component of Heliophysics System Observatory has never been healthier. Comprised of more than 20 state-of-the-art ionospheric and magnetospheric spacecraft, HSO provides direct *in situ* observations of the fundamental physical processes by which geospace dynamics are accomplished. Even with more than 20 strategically placed and well instrumented satellites, however, we still lack quantitative multi-scale information required for understanding how geospace works as a system.

Geospace dynamics are impressed on the upper atmosphere through processes that together are called MIT coupling. IT remote sensing is a powerful compliment to *in situ* observations, and provides our best multi-scale view of geospace dynamics and the impacts of space weather. The recently completed US "Decadal Strategy (DS) for Solar and Space Physics" provides a snapshot of our collective geospace aspirations for the coming years. For this, researchers provided whitepapers that together comprise a kind of "wish list" for space physics. An oft-repeated sentiment was the need for long-term, continuous, multi-scale observations of virtually every parameter of relevance to geospace. In Europe, Canada, Japan, China, and the US, there is an increasing drive to understand geospace as a system, and programs around the world are motivated to meet the truly widespread demand for long-term, continuous, and multi-scale.

Meso- and global-scale IT remote sensing is accomplished via satellite imagers and ground-based instruments. On the ground, the general approach is arrays providing extensive as possible coverage (the "net") and powerful observatories that drill deep to provide detailed information about small-scale processes (the "drill"). Global efforts include SuperDARN and SuperMag, and large regional efforts Meridian, GO Canada, THEMIS-ASI, and MIRACLE. Always, there is a trade between cost, spatial resolution, coverage (extent), number of parameters, and more, such that in general the larger the network the sparser the coverage. Where are we now? There are important gaps. We see processes that quickly evolve beyond the field of view of one ground-based observatory, but involve space/time scales not captured by existing meso- and large-scale arrays. Many of our field's forefront questions require observations at heretofore unexplored space and time scales, and comprehensive inter-hemispheric conjugate observations than are presently available.

Looking forward, although we cannot be cavalier and try to measure every parameter, everywhere, all the time, the next level will require addressing some of these gaps. Meaningful progress requires changes in how we approach ground-based observations and global imaging, how we bridge the full range of scales between small and global, and new technologies including new ways of dealing with data. It requires a new level of international cooperation, where programs funded by one nation would evolve in coordination with those funded by others. It requires recognizing the best approach to big science with ground-based observations and space-based imaging may not be the same as how we make big things happen with major *in situ* missions. Most important, it requires identification of exciting grand challenges, and organizing around them to fill the right gaps in the right way so our steps forward are transformative.

7.2 11:15 - 11:45, *Invited*: Ian Mann: Geospace Science from Ground-based Magnetometer Arrays: Advances in Sensors, Data Collection, and Data Integration

- University of Alberta

Co-author(s): Peter Chi

- *UCLA*

Networks of ground-based magnetometers now provide the basis for the diagnosis of magnetic disturbances associated with solar wind-magnetosphere-ionosphere coupling on a truly global scale. Advances in sensor and digitisation technologies offer increases in sensitivity in fluxgate, induction coil, and new micro-sensor technologies — including the promise of hybrid sensors. Similarly, advances in remote connectivity provide the capacity for truly real-time monitoring of global dynamics at cadences sufficient for monitoring and in many cases resolving system level spatio-temporal ambiguities especially in combination with conjugate satellite measurements. A wide variety of the plasmaphysical processes active in driving geospace dynamics can be monitored based on the response of the electrical current system, including those associated with changes in global convection, magnetospheric substorms and nightside tail flows, as well as due to solar wind changes in both dynamic pressure and in response to rotations of the direction of the IMF. Significantly, any changes to the dynamical system must be communicated by the propagation of long-period Alfvén and/or compressional waves. These wave populations hence provide diagnostics for not only the energy transport by the wave fields themselves, but also provide a mechanism for diagnosing the structure of the background plasma medium through which the waves propagate. Ultra-low frequency (ULF) waves are especially significant in offering a monitor for mass density profiles, often invisible to particle detectors because of their very low energy, through the application of a variety of magneto-seismology and cross-phase techniques. Renewed scientific interest in the plasma waves associated with near-Earth substorm dynamics, including magnetosphere-ionosphere coupling at substorm onset and their relation to magnetotail flows, as well the importance of global scale ultra-low frequency waves for the energisation, transport, acceleration, and loss of electrons in the radiation belts promise high profile science returns. Integrated, global scale data products also have potential importance and application for real-time monitoring of the space weather threats to electrical power grids from geomagnetically induced currents. Such data exploitation increasingly relies on the collaborations between multiple national magnetometer arrays to generate single data products with common file format and data properties. We review advances in geospace science which can be delivered by networks of ground-based magnetometers Ð in terms of advances in sensors, data collection, and data integration — including through collaborations within the Ultra-Large Terrestrial International Magnetometer Array (ULTIMA) consortium.

7.3 11:45 - 12:15, *Invited*: Mike Nicolls: Ground-based radar and radio techniques for Geospace observations

- *SRI International*

The sensing of the near-Earth space environment, geospace, with ground-based radar and radio techniques has evolved considerably with the development of lower-cost technologies and the deployment of arrays of small, remotely operated instrumentation and "instruments of opportunity".

Pertaining to the former, incoherent scatter radar (ISR) sensing has advanced significantly in the past decade with the development of AMISR, a low-cost electronically steerable phased array IS radar and EISCAT-3D, a vision for a large-aperture multi-static ISR. These advances are paving the way for new concepts in ISR development and operations, which will ultimately change the way these instruments are operated from a case-study driven focus to their use in weather, trends, and forecasting. New diagnostics of the neutral atmosphere and ionosphere will be enabled as these technologies mature.

Pertaining to the latter, the widespread deployment and use of dual-frequency GPS receivers for inferring total electron content (TEC) has led to new insights and discoveries. Low-cost access to space has enabled new measurement paradigms using ground-to-space based links. Software-defined and "net-centric" systems have enabled low-overhead operations and deployment to remote locations.

This talk will review a subset of these methods, their use for sensing the space environment, and what is needed to advance high priority science in solar and space physics. Radar-based topics reviewed will include techniques such as ISR, MST, MF, meteor radar, and oblique and vertical incidence HF sounding. Radio techniques reviewed will include passive sensing of signals of opportunity, radiometry, and ground-to-space-based links including TEC measurements.

8 13:15 - 15:00: PARALLEL SESSIONS – Photons, Particles, Fields

8.a Photons – Imaging [North]

Chair(s): D. Rabin

8.a.1 13:15 - 13:45: Brian Ramsey: Developments in X-Ray Optics

- NASA MSFC

X-ray optics have found widespread use in heliophysics and astrophysics. Their imaging properties reveal a wealth of source structure and, particularly for astrophysics, they provide an enormous increase in signal to noise by reducing background to almost zero. The challenge in x-ray-optics development is to provide ever-larger collecting areas and high angular resolutions within manageable budgets. This means developing low-mass mirror systems but with precise figures to ensure optimum performance. This presentation will review the fabrication techniques currently used for x-ray optics and discuss new developments to provide the light-weight, high-resolution optics necessary for future missions.

8.a.2 13:45 - 14:00: Brian Walsh: Wide field-of-view soft x-ray imaging for solar wind-planetary interactions

- Space Sciences Laboratory, University of California - Berkeley

Co-author(s): M. R. Collier[1], K. D. Kuntz[2], F. S. Porter[1], D. G. Sibeck[1], S. L. Snowden[1]
- [1]NASA GSFC, [2]Johns Hopkins University APL

Soft x-ray imagers can be used to study the meso- and macro-scale density structures generated by the plasma processes that occur whenever and wherever the solar wind encounters neutral atoms at comets, the Moon, and both magnetized and unmagnetized planets. Charge exchange between high charge state solar wind ions and exospheric neutrals results in the isotropic emission of soft x-ray photons with energies from 0.1 to 2.0 keV. At Earth, this charge exchange occurs primarily within the magnetosheath and cusps. In contrast to *in situ* measurements, a wide field-of-view soft x-ray imaging can determine the significance of the various proposed solar wind-magnetosphere interaction mechanisms by evaluating their global extent and occurrence patterns. Here we provide a description of wide field-of-view soft x-ray imaging including slumped micropore microchannel reflectors, microchannel detector plates, simulated images, and recent flight results.

8.a.3 14:00 - 14:15: Daniel Seaton: Lessons Learned in Five Years of Observations with the EUV Solar Telescope SWAP onboard PROBA2

- Royal Observatory of Belgium

Co-author(s): David Berghmans[1], Anik De Groof[2], Jean-Philippe Halain[3], Bogdan Nicula[1], Laurel Rachmeler[1]
- [1]Royal Observatory of Belgium, [2]European Space Astronomy Center/ESA, [3]Centre Spatial de Liege

The Sun Watcher with Active Pixels and Image Processing (SWAP) is an EUV solar telescope onboard ESA's Project for Onboard Autonomy 2 (PROBA2) mission launched on 2 November 2009. The SWAP telescope is unique in several aspects, including its relatively large field-of-view (54×54 arcmin), stray-light-limiting off-axis design, and its CMOS-APS detector, the first of its kind used in a space-based instrument in solar physics. In particular, APS sensors like SWAP's offer many advantages over traditional CCDs, including vastly reduced power requirements, simpler electronics, radiation resistance, and the ability to operate without a mechanical shutter. Because of these many advantages, a new generation of APS devices are slated for use on upcoming missions like the formation-flying PROBA3 coronagraph and out-of-ecliptic Solar Orbiter. However, APS detectors come with their own operational challenges as well, and the calibration of APS-derived images can be more complex than CCD-derived images. Here we present an overview of the SWAP imager and discuss a few of the lessons learned in five years of operations and observations with it, with an emphasis on the use of APS detectors in solar physics applications.

8.a.4 14:15 - 14:30: Douglas Rabin: The Next Generation of Coronagraphs: Smaller, Tailored, Distributed

- NASA GSFC

Co-author(s): J. M. Davila, P. C. Chamberlin, N. Gopalswamy, N. Shah
- NASA GSFC

It is timely for several reasons to consider the future of space-based solar coronagraphs. The hugely successful SOHO and STEREO platforms are beyond their nominal operational lifetimes, and no "flagship" satellites suitable for carrying coronagraphs are on the horizon. However, the range of available platforms has expanded to include the International Space Station, hosted geosynchronous platforms, and small satellites with rapidly advancing capabilities. Also, the diagnostic power of a coronagraph can be increased to include temperature and radial outflow speed as well as electron density. The confluence of these factors points to a future in which coronagraphs are smaller, tailored to relatively narrow scientific or operational objectives, and distributed among different types of platforms. We give examples, including a broadly applicable filter-based diagnostic technique (Reginald et al. 2011), a concept for ISS, a concept for L5, and an externally occulted coronagraph using two formation-flying CubeSats.

8.a.5 14:30 - 15:00: Joseph Davila: Milli-Arcsecond Diffractive Imaging of the Sun in the Extreme Ultraviolet

- *NASA GSFC*

Co-author(s): Adrian Daw, Figen Sevinc Oktem, Kevin Denis, John O'Neill, Neerav Shaw
- *NASA GSFC*

The problem of heating the solar corona has been studied for several decades. It was recognized more than fifty years ago that the corona was much hotter than the visible surface of the Sun, but it was not clear why or how the coronal plasma reached temperatures about 1000 times the temperature of the photosphere. Observations by soft x-ray and EUV imagers, which image the high temperature emission lines emitted from ionized iron and other coronal elements, have provided many new clues regarding the nature of the heating, but the still the structure of the heated regions remain unobserved and the mechanism responsible for heating remains unknown. The primary reason for this is that heating is confined to extremely narrow current sheets; sheets where currents are large enough to result in significant dissipation even though the resistivity of the coronal plasma is low. The typical scale of these current sheets could be a few kilometers or less. At these scales, imaging of a few 10-3 arcsec (i.e. few mas) is required to study the structure and development of these dissipation regions. Such data will provide unique information on the heating mechanism, which cannot be inferred from current observations. Current instruments, including SOHO/EIT and SDO/AIA, are two mirror reflecting telescope designs with multilayer coated optics. This type of telescope is relatively simple to build and the multilayer coating provides excellent reflectivity in a narrow band (typically Dl/l of order 10%) in the 5-40 nm wavelength range. Although recent instruments demonstrate significant improvements in spatial resolution, field-of-view, and temporal resolution, it is extremely difficult to manufacture these telescopes to provide mas resolution at a wavelength of order 30 nm. All of these telescopes provide resolution significantly larger than the diffraction limit. To approach diffraction limited imaging the primary and secondary mirrors would need to be manufactured with figure errors of order 2 nm. This accuracy is difficult and/or expensive to achieve at this time on concave and convex optics. Diffractive imaging offers the potential of obtaining extremely high-resolution images using imaging elements with relatively relaxed manufacturing tolerances. There are two major disadvantages to diffractive imaging, (1) the focal lengths are long and (2) the images are highly chromatic. Recent progress in addressing these issues will be discussed.

8.b Particles – Measuring Plasmas [Center]

Chair(s): B. Lavraud, A. Jaynes

8.b.1 13:15 - 13:35, *Invited*: Andrei Fedorov: Plasma Imaging Optics

- *IRAP-UPS-CNRS*

In the modern space plasma diagnostics two instrument properties are always extremely important: 1) the instrument should be capable to provide a 3D charged particles velocity distribution function in one sampling round; 2) the instrument sampling rate should be very high to resolve characteristic plasma processes. For instance the maximal sampling rate of MMS ion spectrometer is 6 Hz.

To achieve such properties, a modern plasma instrument should scan some dimensions (like energy or angle) and make an image snapshot in the other dimensions (usually angle). The present talk is devoted to the review of the evolution history and the modern state of the space plasma imaging sensors. The classical "top hat" electrostatic analyzer was a first advanced technique allowing to make an instant image of the 360° fan-shape field of view and sweep the energy range. If we mount such an instrument onboard of a spinning spacecraft we can obtain a full 3D charged particles distribution function with sampling time equal to the spacecraft spin period. Most of the modern plasma sensors are just a result of enhanced development of this initial idea. The nowadays sensors usually employ the "top hat" analyzer

with many additional features such as:
- electrostatic aperture steering;
- electrostatic control of the geometrical factor;
- spacecraft potential compensation.

Special design features are arriving if the sensor should be well protected from the solar heat and UV fluxes and if the analyzer is the entrance part of a mass-spectrometer. The talk illustrates the variety of the modern approaches on the examples of STEREO, Bepi Colombo, Solar Orbiter and MMS missions.

8.b.2 13:35 - 13:55, *Invited*: Yoshifumi Saito: Low Energy Charged Particle Spectrometers for High Time Resolution Measurements

- ISAS JAXA

Co-author(s): Shoichiro Yokota
- ISAS JAXA

Time resolution required for the low energy charged particle measurements is becoming higher and higher due to the demand for resolving electron scale phenomena. There exist several items that should be developed in order to realize time resolution to acquire 3-D phase space density higher than 10 msec. The 3-D phase space density measurement should be made independent of the spacecraft spin motion. The sensitivity of the analyzer should be high in order to secure good enough counting statistics with short sampling time especially for measuring tenuous plasmas, for example, in the Earth's magnetotail. The charged particle detector should be fast enough to accept high count rate generated by high sensitivity analyzer.

One of the solutions for the 3-D phase space density measurement independent of the spacecraft spin motion is to use two analyzers with hemispherical field of view installed on a spacecraft back to back. An example of such an analyzer is ASKY-ESA (All SKY-ElectroStatic Analyzer) originally developed for the 3-D phase space density measurement on 3-axis stabilized spacecraft. ASKY-ESA consists of FOV (Field Of View) scanning deflectors at the entrance and spherical/toroidal electrostatic deflectors inside. The FOV is electrically scanned between ±45 degrees around the center of the FOV, which is 45 degrees inclined from the axis of symmetry. ASKY-ESA was flight verified as MAP-PACE sensors on Japanese lunar orbiter Kaguya.

In order to realize high sensitivity, an electron energy analyzer FESA (Fast Electron energy Spectrum Analyzer) was developed. FESA consists of two electrostatic analyzers that are composed of three nested hemispherical deflectors. Single FESA functions as four top-hat type electrostatic analyzers that can measure electrons with four different energies simultaneously. By measuring the characteristics of the test model FESA, the validity of the design concept of FESA was proved.

Concerning the fast charged particle detector, an MCP anode with ASIC was developed. In order to use the anode for sounding rockets and satellites, it should be lightweight and low power consumption. We have decided to adopt the anode configuration that discrete anode is formed on 1mm ceramic substrate, and the bare ASIC chip is installed on the backside of the ceramic. The ASIC contains 64-channel fast amplifiers and counters that enable 5.625deg. angular resolution necessary for measuring solar wind ions. Whole ceramic substrate except discrete anode pattern that collect charged particles is parylene coated in order to protect the ASIC and the bonding wires from humidity and dust. It is found that the anode can detect high count rate of 25MHz/channel. The anode has been successfully flight verified by two Norwegian sounding rocket experiments ICI-2 and ICI-3 (Launched from Ny Alesund, Svalbard, Norway in Dec. 2008 and 2011). In the near future, this anode will be used for detecting low energy ions with Mercury Ion Analyzer (MIA) on BepiColombo/MMO. The ASIC chip and its implementation will be widely used for the future missions that require lightweight low power consumption, high time resolution charged particle measurements.

8.b.3 13:55 - 14:08: Glyn Collinson: Calculating the geometric factor of electrostatic analyzers

- NASA GSFC

Co-author(s): John Dorelli[1], Levon Avanov[1,2], Gethyn Lewis[3], Thomas Moore[1], Craig Pollock[1], Dhiren Kataria[3], Robert Bedington[3], Chris Arridge[3,4], Dennis Chornal[1,5], Ulrik Gliese[1,6], Al Mariano[1], Alexander Barrie[1,7], Corey Tucker[1,8], Christopher Owen[3], Andrew Walsh[3], Mark Shappirio[1], Mark Adrian[1]
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We report our findings comparing the geometric factor (GF) as determined from simulations and laboratory measurements of the Dual Electron Spectrometer (DES) optics of the Fast Plasma Investigation on NASA's new Magnetospheric Multiscale mission (MMS). Particle simulations are increasingly playing an essential role in the design and calibration of electrostatic analyzers, facilitating the identification and mitigation of the many sources of systematic error present in laboratory calibration. Starting from first principles, we will explain how to determine the GF of a plasma analyzer in both simulation and laboratory, so that the two may be directly compared. We also discuss how we have estimated errors in both cases. Finally, we apply these equations to the new DES instrument and show that the results agree within errors. Thus we show that the techniques presented here will produce consistent results between laboratory and simulation.

8.b.4 14:08 - 14:21: Andrew Yau: Imaging Thermal Plasma Composition and Velocity Distributions *in-situ* Using Hemispherical Electrostatic and Time-of-Flight Analysis

- *University of Calgary*

Co-author(s): Andrew Howarth, Greg Enno, Andrew White
- *University of Calgary*

We present an imaging thermal ion mass and velocity analyzer that combines a hemispherical electrostatic analyzer (HEA), a time-of-flight (TOF) ion mass spectrometer, and a pair of electrostatic deflectors, for measurements of low-energy (1 -100 eV/e) ion mass composition (1 to >40 AMU/e) and velocity distributions on a non-spinning platform, for example the CASSIOPE Enhanced Polar Outflow Probe (e-POP). Using the HEA to measure the energy-per-charge of each detected ion and the TOF gate to measure the transit time of the ion inside the analyzer, this instrument is capable of resolving all major ion species in the ionosphere including H+, He+ and O+, and adjacent molecular ion species such as N2+, NO+ and O2+ under favorable conditions. In addition, it can image the 2D velocity phase space distributions of each major ion species, and optionally measure the corresponding 3D distributions using the electrostatic deflectors to sample ions out of the sensor's planar aperture. The measured distributions may then be used to derive ion composition, density, drift-velocity and temperature parameters in the ionosphere. We present initial observations of ion outflows and related ion acceleration in the topside ionosphere, to demonstrate the performance capabilities of this instrument on e-POP.

8.b.5 14:21 - 14:34: John Podesta: Errors in the calculation of plasma bulk velocity from the phase space distribution

- *Space Science Institute*

It is important to quantify the experimental uncertainties in the plasma bulk flow velocity and other plasma parameters derived from spacecraft measurements. For electrostatic analyzers, the analysis of these uncertainties is a difficult and complex problem and, consequently, the uncertainties are almost never published despite their importance for users of the data. The macroscopic flow velocity obtained from an electrostatic analyzer contains errors caused by the numerical integration technique used to compute the first moment of the distribution function and, in addition, there are errors caused by the fact that the underlying distribution function measurements themselves contain experimental errors and statistical fluctuations. Here, a simple model is described that quantifies both of these error sources. For simplicity, dead time effects are neglected and the theory is simplified as much as possible. Errors introduced by the approximation of the moment integral by a Riemann sum are estimated using established results from calculus and numerical analysis. Errors in the measurement of the phase space density are assumed to be caused by statistical fluctuations associated with Poisson counting statistics. The resulting theory is used to investigate the following question: What is the minimum phase space resolution required to obtain measurements of the ion bulk velocity with a specified or predetermined accuracy? The results show that for typical solar wind conditions at 1 AU, the measurement of the proton bulk velocity with an accuracy of ± 1 km/s requires that the velocity space distribution of the particles be resolved on a grid of size $\Delta v = 1.7$ km/s and that the relative error of the distribution function measurements must be less than or equal to 0.05% at the peak of the distribution. For a solar wind velocity of 650 km/s, this implies an energy resolution $\Delta E/E = 0.5\%$ and angular resolution $\Delta\theta \approx \Delta v' v = 0.1$ degrees. This represents approximately a factor of ten improvement over the resolution of any electrostatic analyzer ever flown in the solar wind. Measurements of the ion bulk velocity accurate to less than 1 km/s with a time resolution of 1 s are urgently needed to advance knowledge and understanding of fundamental plasma processes in the solar wind. Such data would enable more refined studies of waves and wave-particle interactions at both MHD and kinetic scales, of the angular momentum loss of the sun by the solar wind, the heating of the solar wind by the dissipation of MHD turbulence, the determination of the energy cascade rate of solar wind turbulence using third-order moments of macroscopic plasma variables, the scale dependent angle between fluctuations in the ion bulk velocity and magnetic field fluctuations predicted by turbulence theory, and more. The solar wind and space physics communities need significantly improved plasma instrumentation for future solar wind science missions to enable scientific advances in these and other areas.

8.b.6 14:34 - 14:47: Levon Avanov: Study of Static Microchannel Plate Saturation Effects for the Fast Plasma Investigation Dual Electron Spectrometers on NASA's Magnetospheric MultiScale Mission

- *University of Maryland & NASA GSFC*

Co-author(s): Ulrik Gliese[1], Craig Pollock[2], Thomas Moore[2], Dennis Chornay[3], Alexandr Barrie[4], Joe Kujawski[5], Daniel Gershman[6], Corey Tucker[7], Albert Mariano[2], Darrel Smith[8], Arthur Jacques[2]
- [1]*SGT Inc.*, [2]*NASA GSFC*, [3]*University of Maryland*, [4]*Millenium Engineering and Integration Company*, [5]*Siena College*, [6]*Oak Ridge Associated Universities*, [7]*Global Science and Technology*, [8]*Orbital Sciences Corporation*

Imaging detecting systems based on microchannel plates (MCPs) are the most common for low energy plasma measurements for both space borne and ground applications. One of the key parameters of these detection systems is the dynamic range of the MCP's response to the input fluxes of charged particles. For most applications the dynamic range of the linear response should be as wide as possible. This is especially true for the Dual Electron Spectrometers (DESs) of the Fast Plasma Investigation (FPI) on NASA's Magnetospheric MultiScale (MMS) mission because a wide range of input fluxes are expected. To make use of the full available dynamic range, it is important to understand the MCP response behavior beyond the linear regime where the MCPs start to saturate. We have performed extensive studies of this during the characterization and calibration of the DES instruments and have identified several saturation effects of the detection system. The MCP itself exhibits saturation when the channels lack the ability to replenish charge sufficiently rapidly. It is found and will be shown that the ground system can significantly impact the correct measurement of this effect. As the MCP starts to saturate, the resulting pulse height distribution (PHD) changes shape and location (with less pulse height values), which leads to truncation of the PHD by the threshold set on the detection system discriminator. Finally, the detection system pulse amplifier exhibits saturation as the input flux drives pulse rates greater than its linear response speed. All of these effects effectively change the dead time of the overall detection system and as a result can affect the quality and interpretation of the flight data. We present results of detection system saturation effects and their interaction with special emphasis on the MCP related effects.

8.b.7 14:47 - 15:00: Earl Scime: Low voltage, ultra-compact plasma spectrometer

- *West Virginia University*

Co-author(s): Amy Keesee[1], Drew Elliott[1], Matt Dugas[2], Steve Ellison[2], Joe Tersteeg[2], Graig Pollock[3]
- [1]*West Virginia University*, [2]*Applied Research Corporation*, [3]*NASA GSFC*

Taking advantage of technological developments in lithographic fabrication techniques over the past two decades, we have designed an ultra-compact plasma spectrometer that requires only low voltage power supplies, no microchannel plates, and has a high aperture area to instrument area ratio. The designed target is for ions in the 3 - 20 keV range with a highly directional field of view. In addition to reducing mass, size, and voltage requirements, the new design will revolutionize the manufacturing process of plasma spectrometers, enabling large quantities of identical instruments to be manufactured at low individual unit cost. Such a plasma spectrometer is ideal for Heliophysics plasma investigations, particularly for small satellite and multi-spacecraft missions. Initial key elements of the instrument have been fabricated and we will present design details and current status of testing.

*This work is supported by NASA grant NNX14AJ36G

8.c Fields – Plasma Waves and Space-based Instruments Using EM Waves [South]

Chair(s): C. Swenson, C. Kletzing

8.c.1 13:15 - 13:35, *Invited*: James LaBelle: High Frequency Wave Measurements in Space Plasmas

- Dartmouth College

In the twenty years since the last conference on measurements in space plasmas, space-borne high frequency wave instruments have evolved from being primarily waveform snatchers and swept or stepped frequency analyzers, to being wideband waveform receivers or highly capable combined receivers/digital signal processors. The wideband strategy has been used mostly on sounding rockets which allow high telemetry rates. Receivers with bandwidths 3-5 MHz have been flown in both nightside auroral and cusp environments, and in one case at the equator. Despite limited dynamic range of these instruments, some remarkable highly resolved wave structures have been measured, with implications for microphysics. In particular, significant results have been obtained related to microphysics of Langmuir waves. The receiver/digital signal processor combination has been flown on multiple sounding rockets in auroral and equatorial applications, as well as many prominent satellite missions such as Image, FAST, DEMETER, Cluster, C/NOFs, ePoP, etc. These applications require less bandwidth on average and are extremely flexible, allowing tuning to different frequency ranges with different bandwidths. These instruments typically use digitizers at the front end with bit depths of 14-16 bits or greater, implying high dynamic range. The outcome of these instruments has thoroughly infused the high frequency wave community at this point, leading to significant advances in understanding of a host of wave phenomena ranging from Langmuir waves to AKR.

8.c.2 13:35 - 13:55, *Invited*: Craig Kletzing: A Wave-Particle Correlator with Good Phase Resolution

- University of Iowa

Wave-particle correlations, particularly of Langmuir waves and electron have been the subject of significant interest extending back to the 1970's. Often, these correlations have been simply observing modulation of the electrons at the plasma frequency with no phase resolution. The first phase-resolving correlators were developed at UC Berkeley in the late 1980's and reported by Ergun in the early 1990's. A design is presented which further improves on phase resolution in correlations of Langmuir waves and electrons with phase resolution of 22.5 degrees. In this technique, a phase-lock-loop (PLL) is used to lock onto the wave and subdivide the phase. Electrons are sorted on-the-fly as the arrive into the phase bins. Discussed are details of accurate timing, testing, and calibration of this system as well as results from rocket flights in which statistically significant phase correlations have been observed.

8.c.3 13:55 - 14:15, *Invited*: Attila Komjathy: Space-Borne GNSS (GPS) Receivers and Related New Technologies For Space Physics Measurements and Natural Hazards Monitoring

- NASA JPL

Co-author(s): A.J. Mannucci, E. Shume, O. Verkhoglyadova, O. Yang, X. Meng
- NASA JPL

Scientists are finding transmissions from Global Navigation Satellite System (GNSS) as a useful source of ionospheric observations for a wide variety of scientific applications. Whereas GNSS transmissions were designed to provide navigation data that is free of ionospheric influence, the two transmitted frequencies can be combined to provide highly precise measurements of ionospheric total electron content (TEC) variations along the straight-line signal path between the transmitters and a receiver in low Earth orbit. Absolute TEC is recovered if interfrequency biases originating in the receiver and transmitting satellites are estimated. Receivers in low Earth orbit can recover local electron density based on simple geometrical considerations local to the satellite, and local TEC perturbations have been retrieved from inter-satellite ranging links using data e.g., from the Gravity Recovery and Climate Experiment (GRACE) spacecraft.

In this talk, we provide a survey of the science and space weather applications to which space-based TEC observations are being applied. The limb geometry of the observations permits an approximate retrieval of vertical electron density profiles. The highly precise measurements (< 0.1 TECU) are sensitive to ionospheric irregularities along the raypath between transmitter and receiver. The spectral content of the TEC fluctuations can be used to infer the spatial scale sizes of the intersected irregularities. In space weather applications, satellite-based TEC is often combined with TEC data from ground-based receiver networks to form tomographic measurement geometries from which global electron density is accurately retrieved and monitored using e.g., assimilative ionospheric modeling approaches.

Furthermore, we will describe specific science applications of GNSS TEC including new implementations at high latitudes and for imaging the impacts of natural hazards such as tsunamis, earthquakes and meteor impacts. By studying the propagation properties of small changes in GNSS TEC observations generated by natural hazards along with applying sophisticated physics-based coupled surface-thermosphere-ionosphere modeling techniques, scientists are on track to develop new technologies that can potentially save human lives and minimize property damage. We will provide a survey of GNSS TEC missions and the prospects for expansion of these data sets including the augmentation of ground-based GPS networks with novel space-based platforms to improve retrieval accuracies using e.g., ever-smaller but highly capable GNSS TEC instruments.

8.c.4 14:15 - 14:35, *Invited*: Charles Swenson: Impedance Probe Measurements in the Ionosphere

- Utah State University

The impedance at RF frequencies of an antenna immersed in ionospheric plasma is important both for its use as a diagnostic tool and for its effects on space systems. The antenna strongly interacts at characteristic plasma frequencies, producing distinct magnitude and phase transitions in the impedance frequency curve. This has become the basis of a method for plasma density diagnostics used over the last 45 years. To first order, the impedance, at small signal levels, is dependent on the average dielectric properties of the volume encompassed by the near field of the antenna. It is independent of the surface characteristics of the antenna and spacecraft floating potential. The most common antennas used in theory and experiment in the past decades has been that of a short dipole or monopole. Two general classes of probes, the Plasma Frequency and the Sweeping Impedance Probes, have been designed around these observed effects. In this paper we review basic impedance probe theory and application to measurement implementation. We present data from different impedance probes on the ISS and sounding rockets including the recent Auroral Spatial Structures Probe (ASSP) and Mesosphere-Lower Thermosphere Turbulence Experiment (M-TEX) missions.

8.c.5 14:35 - 14:55, *Invited*: Ivan Galkin: Active Space-borne Radio Sensing of Ionosphere and Magnetosphere

- University of Massachusetts - Lowell

Co-author(s): Bodo Reinisch
- Lowell Digisonde International, LLC

Active radiowave sensing of plasma from space-borne observatories is often regarded as an "imaging" technique for its ability to characterize not only ambient but also remote space plasmas as far as 50,000 km away from the spacecraft. With a growing interest in remote sensing by flying observatory formations and the development of low-power, miniaturized wave instrumentation, the 2D/3D radio plasma imagers are becoming an essential tool for determining the large-scale responses of geospace to solar wind disturbances. A modern space-borne radio sounder combines multiple plasma sensors in one package: (1) a resonance relaxation sounder for accurate, non-distorting *in-situ* plasma specification, (2) a stepped-frequency specular-reflection radar for 1D plasma density evaluation along the signal propagation paths, and (3) a passive receiver for spectral and temporal analysis of background radio emissions. In combination with other collaborative sensors, radio plasma imagers can be used for tomography computation and intricate wave propagation studies. We will present a brief review of missions involving the active radio sensors, discuss challenges and solutions for transmission experiments in space plasma, outline the range of data products available for space physics research, and discuss intelligent techniques for data prospecting and interpretation. Specific examples of radio sensors will include the Radio Plasma Imager (RPI) on NASA's IMAGE with its unique capability to measure the electron density distribution along geomagnetic field lines, the Very-Low-Frequency Transmitter for AFRL's DSX mission, and the 3-axis Double-Probe & Topside-Ionosphere-Sounder (DPTIS) currently under development for an AFRL mission. DPTIS will provide real-time vertical electron density profiles from the spacecraft altitude (nominally 800 km) down to the F2 layer peak together with *in situ* electric field measurements.

14:55 - 15:00: Discussion

9 15:15 - 17:00: PARALLEL SESSIONS – Photons, Particles, Ground

9.a Photons – Imaging [North]

Chair(s): S. Mende

9.a.1 15:15 - 15:30: Anthony Yu: Development of a Sodium LIDAR for Spaceborne Missions

- NASA GSFC

Co-author(s): Michael Krainak, Diego Janches, Sarah Jones, Branimir Blagojevic, Jeffrey Chen
- NASA GSFC

We are currently developing laser and electro-optic technologies to remotely measure Sodium (Na) by adapting existing lidar technology with space flight heritage. The developed instrumentation will serve as the core for the planning of a Heliophysics mission targeted to study the composition and dynamics of Earth's mesosphere based on a spaceborne lidar that will measure the mesospheric Na layer. There is a pressing need in the Ionosphere – Thermosphere - Mesosphere (ITM) community for high-resolution measurements that can characterize small-scale dynamics (i.e. Gravity Waves with wavelengths smaller than a few hundred km) and their effects in the Mesosphere-Lower-Termosphere (MLT) on a global basis. This is compelling because they are believed to be the dominant contributors to momentum transport and deposition in the MLT, which largely drive the global circulation and thermal structure and interactions with the tides and planetary waves in this region. We are developing a spaceborne remote sensing technique that will enable acquisition of global Na density, temperature and wind measurements in the MLT with the spatial and temporal resolution required to resolve issues associated with the structure, chemistry, dynamics, and energetics of this region

A nadir-pointing spaceborne Na Doppler resonance fluorescence LIDAR on board of the ISS will essentially make high-resolution, in time and space, Na density, temperature and vertical wind measurements, from 75-115 km (MLT region). Our instrument concept consisted of a high-energy laser transmitter at 589 nm and highly sensitive photon counting detector that allows for range-resolved atmospheric-sodium-temperature profiles. The atmospheric temperature is deduced from the linewidth of the resonant fluorescence from the atomic sodium vapor D2 line as measured by our tunable laser. We are currently developing a high power energy laser that allows for some day time sodium lidar observations with the help of a narrow bandpass filter based on etalon or atomic sodium Faraday filter with ∼5 to 10 pm optical bandwidth. The current baseline detector for the lidar instrument is a 16-channel Photomultiplier Tube with receiver electronics that has been space-qualified for the ICESat-2/ATLAS mission. Our technique uses the 16-channels as a photon-number-resolving "single" detector to provide the required full-spectroscopic sodium lineshape waveform for recovering Mesospheric temperature profiles. In this paper, we will describe our instrument concept for a future Heliophysics space mission based on board of the International Space Station (ISS).

9.a.2 15:30 - 15:45: Stephen Mende: The ICON FUV Imager

- University of California - Berkeley

Co-author(s): CC. Chou[1], J. J. Loicq[2], C. Kitzinger[2], H. U Frey[1], S. E. Harris[1], S. Ellis[3], T. J. Immel[1], S. L. England[1], W. Craig[1], C. Wilkins[1]
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A novel design FUV spectrographic imager is currently under construction at UC Berkeley for the payload of the Ionospheric Connection Explorer (ICON). This instrument will image the limb-view atmosphere/ionosphere with a FOV of 24x18 degrees (vertical and horizontal) tilted down by 20° and looking in a direction nominally perpendicular to the spacecraft velocity. From the spacecraft altitude (575 km) the view provides coverage from sub-limb up to ∼500 km limb tangent height. There is a steering mirror assembly that allows steering the view ±30° with respect to the nominal direction in order to observe the nightglow emissions along the local magnetic meridian. The instrument uses the spectrographic imager principle first used on the IMAGE spacecraft in which several full two-dimensional instantaneous images are formed in specific wavelength bands. One of the two bands on ICON contains the 135.6 nm atomic oxygen emission while the other band covers the N2 LBH emission region near 157 nm. When the imager is viewing the sunlit atmosphere the instrument provides the limb altitude profile of the atmospheric O/N2 ratio. On the night side the instrument observes the 135.6 nm emission that is produced by the recombination of O+ and therefore provides a good proxy for the nighttime ionospheric density distribution. To minimize data downlink, 6 parallel vertical stripe segments will be transmitted to the ground from both channels every 12 seconds. In addition the nighttime 135.6 nm data will be integrated as two dimensional (spacecraft orbit latitude and longitude) maps. One map is projected on a sphere at 300 km altitude while the other map projects at a surface defined by the tangent height of observation from the ICON satellite. Both maps will be generated by integrating the detector signal while using motion compensation to minimize blurring due to the satellite orbital speed.

9.a.3 15:45 - 16:00: Iraida Kim: Stokes Parameter Imaging in the Low K-corona

- Lomonosov Moscow State University

Successful recording I, Q, U, and V Stokes parameters of the faint objects near the bright ones, particularly, structures of the upper solar atmosphere in the range < 1.4 Rsun, is defined by the acceptable level of stray light in telescopes. Reducing the stray light by the Lyot method, a multiple cascade coronagraphic technique, the use of super-smooth or moderately smooth with a given profile of a microrelief primary optics are briefly noted. The efficiency of the other two ways to reduce the stray light is analyzed. They are different from the classical coronagraphic one and allow the use of telescopes with a simplified optical scheme. Recent technology advances allow the consideration of a new generation coronagraph with a variable transmission of an entrance aperture. Calculated efficiency is at least 2-3 orders of magnitude higher than in a Lyot-type coronagraph. Another approach is based on ground and space total solar eclipses. "Polarization images" (2D distributions of the polarization degree, the polarization angle, and the sign of the angle) and 2D distributions of the relative color index of the K-corona are shown to demonstrate advantages of total solar eclipse programs. Calculated dependences of the expected level of the stray light on distance are compared for ground (scattering at the Moon "profile") and artificial space total solar eclipses: Artificial Solar Eclipse Experiment during the Apollo-Soyuz Test Project, Proba 3, near Mercury orbits).

9.a.4 16:00 - 16:15: Craig Unick: Selection of FUV Auroral Imagers for Satellite Missions

- University of Calgary

Co-author(s): Eric Donovan[1], Emma Spanswick[1], Vadim Uritsky[2]
- [1] *University of Calgary,* [2] *NASA GSFC*

A survey of previously flown and recently designed FUV auroral imagers is presented in conjunction with selection criteria to optimize the potential scientific impact of future satellite based FUV auroral observations.

9.a.5 16:15 - 16:30: Marc Lessard: The Fast Auroral Imager (FAI) for the e-POP Mission

- University of New Hampshire

Co-author(s): Leroy Cogger[1], Andrew Howarth[1], Andrew Yau[1], Andrew White[1], Greg Enno[1], Brent Sadler[2]
- [1] *University of Calgary,* [2] *University of New Hampshire*

The Fast Auroral Imager (FAI) is part of the Enhanced Polar Outflow Probe (e-POP) instrument suite on the Canadian Cassiope small satellite, which was launched by Space Exploration Technologies Corporation (SpaceX) from Vandenberg Air Force Base on September 29, 2013 into a 325x1500 km elliptical orbit at 81° inclination. The Fast Auroral Imager (FAI) consists of two charge-coupled device (CCD) cameras: one to measure the 630 nm emission of atomic oxygen in aurora and enhanced night airglow; and the other to observe the prompt auroral emissions in the 650 to 1100 nm range. High sensitivity is realized through the combination of fast lens systems (f/0.8) and CCDs of high quantum efficiency (>90 % max). The cameras have a common 26 degree field-of-view to provide nighttime images of about 650 km diameter from apogee at 1500 km. The near infrared camera provides up to two images of 0.1 s exposure per second with a spatial resolution of a few km when the camera is pointing in the nadir direction, making it suitable for studies of dynamic auroral phenomena. The 630-nm camera has been designed to provide one image of 0.5 s exposure every 30 seconds. Onboard e-POP, the FAI can be operated in different modes, including a nadir-pointing and a target-acquisition mode. In this talk, we show results from the imager, highlighting its exceptional sensitivity and overall performance.

9.a.6 16:30 - 16:45: Kenneth Dymond: The Tiny Ionospheric Photometers on the COSMIC Constellation

- Naval Research Laboratory

Co-author(s): Scott A. Budzien, Damien H. Chua, Clayton Coker
- Naval Research Laboratory

The Constellation Observing System for Meteorology, Ionosphere, and Climate (FORMOSAT-3/COSMIC) is a constellation of six microsatellites that was launched into low-Earth orbit on April 14, 2006 and continues to operate at present (April 2014). Each FORMOSAT-3/COSMIC satellite contained a GPS Occultation Experiment (GOX) GPS receiver, a Tiny Ionospheric Photometer (TIP), and a Tri-band Beacon (RF beacon), which were used to measure the ionosphere. The TIP photometers operated from April 2006 through 2010, when they were turned off to help conserve power. This paper describes the TIP photometers, their calibration, on-orbit performance, and summarizes some scientific results.

9.a.7 16:45 - 17:00: Qian Gong: Mirrorlet Based Integral Field Spectrometer for Solar Eruptions

- NASA GSFC

The solar atmosphere is rich with rapid, dynamic events that occur constantly such as spicules, nanoflares, and solar wind flows, and also less frequent but larger Solar Eruptive Events, such as solar flares and Coronal Mass Ejections. All of these are part of a system that can drive physical changes to Earth and have major consequences to its space- and ground-based technological assets. Major advances in this field require simultaneous spatial and spectral information in order to determine and distinguish between the mass and energy transport processes that take place during these events. Traditional 2D imagers, such as SDO/AIA, SOHO/EIT, SOHO/LASCO miss spectral information that, through doppler shifts, can give plasma velocity information. Spectrometers, such as SDO/EVE, can give spectral and Doppler information from 'Sun-as-a-star' observations, but the lack of spatial information leaves uncertainty where the flows and energy transport occur.

This problem is traditionally, but not completely, improved by slit-spectrometers such as SOHO/CDS, SOHO/SUMER, and IRIS. These slit-spectrometers can still only give 1D of spatial information then must scan to obtain the second spatial dimension. This scanning time is often greater than the time scale of some of the eruptive events, which can have large changes on the order of seconds, and also the slit image must be lucky to be pointed in the correct spot when erupting. There still lacks many conclusive results from the instruments on spatial vs temporal changes as the instrument scans.

An EUV spectrometer with simultaneous 3D information - 2D of spatial imaging and one of high spectral resolution - is required for such a mission. An Integral Field Spectrometer (IFS) is a perfect solution for such an application. To date there are basically three types of IFS existing: lenslet based, slicer based, and fiber based. However, none of the three can be used for the EUV wavelength range where these solar eruptive events are easily seen. This is because the available lenslet and fiber do not transmit the wavelengths at or below 121.6nm. The slicer based IFS can be made all reflective, but it needs extra mirrors before the spectrometer, which not only drives the cost up, but also reduces the throughput due to the relative low reflectance of the mirrors. An innovative mirrorlet has successfully solved this problem. By replacing lenslet array with mirrorlet array, the simplicity and compactness of the lenslet is kept, while the EUV wavelengths to study eruptive events are efficiently reflected by the mirrorlet.

The prototype mirrorlet IFS setup and result in visible wavelengths will be presented. For the first solar IFS instrument designed, the Lyman Alpha Solar Spicule Observatory (LASSO), and its optical design, image quality, and spectral resolution will be discussed. The detector selection and signal to noise ratio will be addressed, as well as the fabrication and throughput of the critical components, such as grating and mirror coating.

9.b Particles – Tomorrow's Instruments [Center]

Chair(s): G. Collinson

9.b.1 15:15 - 15:35, *Invited*: Craig Pollock: The Fast Plasma Investigation on NASA's Magnetospheric MultiScale Mission: A Case Study in Multi-Instrument Manufacture and Test

- NASA GSFC

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The Fast Plasma Investigation is comprised of 64 top hat plasma spectrometers (32 for ions and 32 for electrons), in addition to 4 Instrument Data Processing Units (IDPUs). Development of so many plasma instruments for a single mission is unprecedented, and has required innovations in design, manufacturing, test, calibration, and operational approach. Since *in situ* phase space density distributions are to be assembled from multiple spectrometers, an increased demand is placed on the precision with which the hardware is manufactured and tested. The simple processing via routine bench testing and characterization of so many assemblies has required the design and implementation of automated test stations. Similarly, the environmental testing and calibration of these instruments has required a level of automation and discipline, both in the execution and in the trending and review of the results and, indeed, has led to new paradigms in instrument testing for space flight. In this paper we will summarize the most important challenges faced in the development of the FPI, the solutions to these challenges, the effectiveness of these solutions, and new approaches to instrument development and test that have grown out of these experiences.

9.b.2 15:35 - 15:55, *Invited*: Martin Wieser: The SWIM-family of miniature ion mass analyzers

- *Swedish Institute of Space Physics*

Co-author(s): Stas Barabash
- *Swedish Institute of Space Physics*

Over the last 15 years the Swedish Institute of Space Physics developed and mastered a line of miniaturized ion mass analyzers for space plasma studies with masses of 400 – 600 g and highly compact and dense design to minimize the volume. The sensors cover an energy range few eV and up to 15 keV, reach the coverage up to hemispherical (depending on application), and mass resolution up to 8. The experience with this line of sensors demonstrates that a sensor mass of 400 – 600 g is a limit in a trade-off between scientifically valuable performance and the sensor weight. The Solar Wind Monitor (SWIM), one of the sensors of the Sub-keV Atom Reflecting Analyzer (SARA) on board of the Indian Chandrayaan-1 mission to the Moon (2005), was the first sensor in the line. A number of instruments derived from SWIM were built, each using the same basic architecture but adapted for the needs of the corresponding mission:
a) the Miniature Ion Precipitation Analyser (MIPA) on ESA's Bepi Colombo mission to Mercury (2017) with an entrance system capable to withstand direct sun exposure at Mercury (operation temperatures up to 450° C) and near hemispherical coverage.
b) the Detector for Ions at Mars (DIM) on the Russian Phobos-Grunt mission (2011) to Mars and the Yinghuo Plasma Package Ion sensor (YPPi) built for the Chinese Yinghuo-1 spacecraft (2011) for Mars, both modified for hemispherical coverage and different thermal environments.
c) the Prisma Ion Mass Analyzer (PRIMA) on the Swedish technology mission PRISMA (2010), adapted for low energy measurements and higher mass resolution measurements using electrical gater and micto mechanical (MEMS) shutter.
d) the eXtra Small Analyzer of Neutrals (XSAN) for the Russian Luna-Glob lander (2018), modified with a charged particle deflection system and a change conversion surface to measure energetic neutral atoms at the lunar surface.
e) the Laboratory Ion Scattering Analyzer (LISA)

built for the laboratory investigation of ions scattered from surfaces (2015).

We review and compare performance and fields of application of the instruments in this family and give an outlook on further developments.

9.b.3 15:55 - 16:08: Stas Barabash: Particle Environment Package (PEP) for the ESA JUICE mission

- IRF-Kiruna

Co-author(s): Pontus Brandt, Peter Wurz, PEP team
- Johns Hopkins University APL, UBe

PEP is a suite of six (6) sensors arranged in three (3) units to measure charged and neutral particles in the Jupiter magnetospheres and at the moons to answer the following overarching science questions: (1) How does the corotating magnetosphere of Jupiter interact with the environment of magnetized Ganymede and non-magnetized Europa and Callisto? (2) What are the governing mechanisms and their global impacts of release of material into the Jovian magnetosphere from Europa and active Io? (3) How do internal and solar wind drivers cause such energetic, time variable and multi-scale phenomena in the steadily rotating giant magnetosphere of Jupiter?

PEP measures positive and negative ions, electrons, exospheric neutral gas, thermal plasma and energetic neutral atoms present in all domains of the Jupiter system over nine decades of energy from $<$ 0.001 eV to $>$ 1 MeV with full angular coverage. PEP provides the instantaneous measurements of plasma flows combined with global imaging via remote sensing using energetic neutral atoms (ENA). PEP will first-ever directly sample of the exospheres of Europa, Ganymede, and Callisto with extremely high mass resolution ($>$ 1100).

PEP plasma dynamics and composition sensor is based the reflectron and reflecting surface technique and provides instantaneous hemispheric distributions of positive and negative ions in the range 10 eV – 40 keV. It also has electron measurement capability. The electron sensor installed on the opposite side of the spacecraft provides instantaneous hemispheric distributions of electrons in the range 10 eV – 50 keV and has ion measurement capabilities. Ultra-lightweight energetic electron sensor built on the Galileo energetic particle detector technique provides instantaneous pitch-angle distributions and spectra of electrons in the range 25 keV – 1 MeV. Low energy ENA camera (10 eV – 3 keV) is based on the conversion surface technique. Energetic neutrals and ions camera combines energetic ion and ENA imaging capabilities and is based on Cassini, IMAGE and Juno. Neutral gas and ion mass spectrometer is a time-of-flight reflectron.

The PEP sensors are designed and optimized to mitigate both high radiation doses and high instantaneous fluxes of the penetrating radiation. PEP radiation mitigation strategy includes (1) passive shielding to reduce total dose and backgrounds, (2) coincidence schemes up to triple to increase signal-to-noise ratio, (3) reduction of the detector sensitive area to reduce background rates keeping foreground sensitivity same by employing focusing electrostatic optics, (4) reduction of the sensor volumes to decrease the internal surface areas emitting not-valid secondary electrons, (5) monitoring instantaneous background rates to be subtracted, (6) replacement of microchannel plates (MCP) by radiation insensitive Ceramic Channel Electron Multipliers (CCEM), where feasible.

9.b.4 16:08 - 16:21 13.0: Joan Stude: The Jovian Plasma Dynamics and Composition Analyzer on JUICE

- Swedish Institute of Space Physics

Co-author(s): Martin Wieser, Stas Barabash
- Swedish Institute of Space Physics

The Jovian plasma Dynamics and Composition analyzer (JDC) is one of six sensors within the Particle Environment Package (PEP) on ESA's JUICE mission to Jupiter. JDC measures 3D distribution functions of positive and negative ions (incl. electrons) in the energy range 1 eV per charge to 41 keV per charge. Full Angular coverage (2 π) is achieved with 16 radial sectors and scanning electrostatic deflectors. A time-of-flight section is used to determine ion masses simultaneously with high sensitivity but low mass resolution and lower sensitivity but high mass resolution.

Instrument mass constraints and the Jovian radiation environment drive the design of the sensor: a compact electrostatic analyzer with spherical sectors, start signal generation by surface interaction on window-blind like slats and a reflectron-type time-of-flight section. Together with optimized detectors, coincidence and anti-coincidence systems, these mitigation strategies will allow JDC to operate at higher background levels and the allocation of heavier shielding.

We present the JDC sensor principle and design, its predicted performance in the Jovian environment and compare to laboratory measurements from JDC sensor prototypes.

9.b.5 16:21 - 16:34: Benoit Lavraud: AMBRE_NG: A compact dual ion-electron spectrometer for thermal plasma measurements

- IRAP/CNRS/UIniversité de Toulouse, Centre National d'Etudes Spatiales

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The Active Monitor Box of Electrostatic Risks (AMBRE) is a double-head thermal electron and ion electrostatic analyzer (~0 – 30 keV) that will be launched onboard the Jason-3 spacecraft in 2015. The new generation AMBRE instrument (AMBRE_NG) constitutes a significant new evolution that will be based on a single head with newly developed sub-systems to reduce all instrument resources. We will describe the main developments which are being made to reach such a dual ion-electron instrument on the order of 1 kg and 1.5 W. The first purpose of AMBRE_NG is the monitoring of spacecraft charging and of the plasma populations at the origin of this charging. The design is also fully appropriate for the study of space plasma processes in the Earth's magnetosphere, as well as at other planets where time resolution may not prevail over mass constraints.

9.b.6 16:34 - 16:47: Robert Michell: APES: Acute Precipitating Electron Spectrometer: A high time-resolution mono-directional electron spectrometer

- University of Maryland & NASA GSFC

Co-author(s): Marilia Samara, Guy Grubbs II
- NASA GSFC, University of Texas - San Antonio

We present a description of the Acute Precipitating Electron Spectrometer (APES) that was designed and built for the Ground-to-Rocket Electron Electrodynamics Correlative Experiment (GREECE) auroral sounding rocket mission. The concept for APES was to measure the precipitating electron spectrum with high-time resolution, on the order of milliseconds. The trade-off made in this case for doing high time resolution was to limit the aperture to only one look direction. The energy selection was done by using a strong permanent magnet to separate the incoming electrons, such that the different energies would fall onto different regions of the Micro-Channel Plate and therefore produce a signal on different anodes. A rectangular MCP was used (15 mm x 100 mm) and there were a total of 50 discrete anodes under the MCP, each one being 15 mm x 1.5 mm, with a 0.5 mm spacing between anodes. The target energy range of APES was 200 eV to 30 keV.

9.b.7 16:47 - 17:00: Dhiren Kataria: Miniaturised *in-situ* particle environment monitor for future space weather missions

- MSSL - University College London

Co-author(s): Hubert Hu[1], Mark Hailey[1], Richard Cole[1], David Rodgers[2]
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In-situ monitoring of the plasma and radiation environment is essential for space-weather early warning systems and for taking potential mitigation actions during, e.g., CMEs. The Hot Plasma Environment Monitor (HoPE-M) is a low resource particle detection system being developed under ESA contract for satellites in Geostationary Orbits. HoPE-M will combine an electrostatic analyser with an energetic particle detection system to provide *in-situ* measurements of the low to medium energy plasma for space weather monitoring. The electrostatic analyser is a combined electron-ion analyser and is designed to measure their energy distribution functions. The energetic particle detection system will extend the energy range to enable measurement of solar energetic and radiation belt particles.

This paper will briefly present measurement requirements, details of the HoPE-M sensor and discuss expected performance. A breadboard system consisting of the electrostatic analyser is currently being tested. Simulation and performance results from the instrument will also be presented and discussed. The complete instrument to include the detector and the sensor electronics is estimated to weigh less than 650 gms and draw 1 W.

9.c Ground – Optical 1 [South]

Chair(s): M. Samara

9.c.1 15:15 - 15:35, *Invited*: Robert Michell: Quantifying spatio-temporal characteristics in auroral structures

- *University of Maryland & NASA GSFC*

There is a wealth of information contained in auroral images, both in the temporal changes and the spatial variations. The challenge of analyzing auroral imaging data—especially at video frame rates and higher—has been to actually quantify the information contained in the auroral images. We discuss methods of extracting and quantifying the temporal and spatial information from auroral images, including spectrograms and spatial Fast Fourier Transforms. These techniques can be applied to data from various fields of view and frame rates, from narrow to all-sky and from slow to high cadence, depending on the science target of the observations.

9.c.2 15:35 - 15:55, *Invited*: Mark Conde : Mapping Thermospheric Air Parcel Transport Trajectories via a Large Scale Ground Based Array of Optical Doppler Spectrometers

- *University of Alaska*

Co-author(s): Don Hampton, Manbharat Dhadly, John Meriwether, John Makela, Aaron Ridley
- *Clemson University, University of Illinois, University of Michigan*

Observational evidence accumulated in recent years shows that the F-region thermospheric wind field responds to magnetospheric forcing in the auroral zone on much smaller spatial and temporal scales than previously expected. Local flows with widths as narrow as 100 km can develop in as little as 15 minutes. Both the spatial an temporal scales of these flows are factors of 2-3 smaller than had generally been expected. The formation of such flows have many consequences, the most challenging of which is to quantify their impact on transport and mixing of air parcels by thermospheric winds. To map out the transport trajectories of air parcels requires observations of the wind field over large geographic regions (at least synoptic scale), for long periods of time (many hours), while still resolving the finest spatial and temporal flow variations present in the actual wind field.

The only technique currently available to provide these spatially extended data with continuous temporal coverage would be via a continental-scale ground-based array of optical Doppler spectrometers. Several smaller regional arrays have now been deployed, by a few different groups. Preliminary results presented here show that these arrays can already provide the required wind data over small geographic regions. Extending the geographic coverage of these existing arrays would, for the first time, allow us to understand in detail how magnetospheric storms can impact heavily populated mid-latitudes via disturbed air masses transported equatorward from the polar regions, where most of the storm energy is originally deposited.

9.c.3 15:55 - 16:08: Marilia Samara: High time resolution multi-spectral imaging: Mesoscale 2D photometry for auroral precipitation estimates

- *NASA GSFC*

Co-author(s): Robert Michell, Guy Grubbs II, Don Hampton
- *University of Maryland & NASA GSFC, University of Texas, University of Alaska*

We present a technique for characterizing the auroral energy input into the ionosphere using ground-based imaging because a realistic representation of the aurora is missing from global ionospheric models. The Multi-Spectral Observatory of Sensitive Electron Multiplying Charge-Coupled Devices (MOOSE) consists of five Andor Ixon DU-888 imagers and is utilized in order to estimate the precipitating electron distributions from measured auroral emission line ratios. These techniques can then be applied over larger scales and longer times, resulting in a more accurate representation of the aurora. MOOSE has been routinely operated, primarily in Alaska, since 2011, collecting multi-spectral auroral image data with different fields of view. Since that time there have been Defense Meteorological Satellite Program (DMSP) satellite overpasses of the MOOSE imagers, such that the actual precipitating electrons can be compared to the emission line ratios (at 1-second cadence) in an attempt to improve the methods of estimating the electron energy from them.

Furthermore, in order to compare against an active aurora event at high cadence (16 Hz frame rate), the Ground-to-Rocket Electrodynamics-Electrons Correlative Experiment (GREECE) sounding rocket was launched into a dynamic post-midnight auroral arc eventâ rich in particle and wave signaturesâ that occurred directly over the down-range imaging site of Venetie, AK.

9.c.4 16:08 - 16:21: Donald Hampton: Methods for estimating regional auroral electron energy deposition from ground-based optical measurements.

- Geophysical Institute University of Alaska - Fairbanks

Co-author(s): Mark Conde[1], M. Jason Ahrns[1], Kristina Lynch[2], Matt Zettergren[3], Stephen Kaeppler[4], Michael Nicolls[4]

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Auroral electron precipitation forms a complex and dynamic energy input into the high-latitude ionosphere and thermopshere. Rapid changes in plasma density due to electron impact ionization create correspondingly rapid changes in conductivity which in turn change the magnitude and altitude profile of joule heating in the E- and F-region. Modeling these changes in the ionosphere and their effects on the local or regional upper atmosphere requires detailed input over wide regions. In support of the AMISR PINOT campaign and several rocket campaigns (CASCADES-2, MICA, ASSP) we have investigated several methods using purely ground-based optical measurements to determine the characteristics of auroral input in geometries away from magnetic zenith. The use of the N2+ first negative emissions at 427.8 nm reproduces the total energy flux over a wide region, but alone does not indicate the altitude profile of this energy deposition. Determining the energy distribution of the precipitating electrons via automation has been more difficult, especially when observing away from magnetic zenith. We describe two basic methods and discuss their strengths and weaknesses. One method is to use altitude profiles of specific emissions and match them to altitude profiles calculated from electron transport models. The incident electron distribution can be estimated by varying the energy distribution used in the model and determining the best match to the observed profile. The second method makes use of the temperature variations observed in a wide-field Fabry-Perot interferometer (Scanning Doppler Imager, SDI) when observing the atomic oxygen green-line emission (557.7 nm). The rapid variations in temperature observed by the SDI during active aurora is due to variations in emission altitude (due to average energy variations) sampling along the steep temperature curve of the lower thermosphere. By comparing the measured temperature to a model temperature profile (MSIS) the emission altitude is found and matched to emission profiles calculated with an electron transport code. Comparing both methods to *in-situ* and ISR measurements show that the profile method is more accurate, but is harder to automate. A successful automated method for producing energy deposition maps of reasonable resolution over a wide geographic area will certainly require a hybrid of ground-based and orbital optical data as well as *in-situ* particle measurements, and ISR data.

9.c.5 16:21 - 16:34: John Noto: A Novel Fabry-Perot Sensor for Atmospheric Sensing

- Scientific Solutions Inc.

Co-author(s): Sudha Kapali, Michael Migliozzi, Juanita Riccobono, Robert Kerr

- Scientific Solutions Inc.

Presented here is a novel geospace sensor capable of providing critical information about the state of the Earth's neutral atmosphere. This "Doppler imager" remotely measures winds and temperatures of the neutral background atmosphere at ionospheric altitudes of 87-300Km and possibly above. Deployed in both ground and space-based modalities, this cost-disruptive technology will allow computer models of the space weather phenomenon, ionospheric variability, to operate with higher precision. This instrument could be flown inexpensively on one or more CubeSats to provide valuable data to space weather forecasters and ionospheric scientists.

Valuable space-weather measurements, neutral wind vector velocity and neutral temperatures are provided by this Doppler imager, even within the restricted CubeSat environment. The CubeSat bus offers a very challenging environment, even for small instruments. The lack of SWaP and the challenging thermal environment demand development of a new generation of instruments; the Doppler imager presented is well suited to this environment.

Concurrent with this CubeSat development is the development and construction of ground based arrays of inexpensive sensors using the proposed technology. Arrays of magnetometers have been deployed for the last 20 years [Alabi, 2005]. Other examples of ground based arrays include an array of white-light all sky imagers (THEMIS) deployed across Canada [Donovan et al., 2006], oceans sensors on buoys [McPhaden et al., 2010], and arrays of seismic sensors [Schweitzer et al., 2002]. A comparable array of Doppler imagers can be constructed and deployed on the ground, to compliment the CubeSat data.

9.c.6 16:34 - 16:47: John Meriwether: Recent applications of the narrow-field Fabry-Perot interferometer to the measurement of polar, mid-latitude, and equatorial thermospheric winds and temperatures

- Clemson University

Co-author(s): Jonathan Makela
- University of Illinois - Urbana-Champaign

The development of the imaging Fabry-Perot interferometer (FPI) to provide ground-based measurements of the thermosphere wind and temperature by line-of-sight observations of the 630-nm nightglow or auroral emission of the metastable atomic O(1D) state has led to major advances in the understanding of upper atmosphere dynamics in all regions of the globe. This progress has been enabled by two factors in the design of the imaging FPI. First, the replacement of the photomultiplier with a low-noise, back-thinned CCD camera with high quantum efficiency results in an increase in FPI sensitivity relative to a pressure-scanning FPI by nearly two orders of magnitude. Second, the imaging of multiple interference orders simultaneously increases the FPI instrumental throughput by broadening the instrumental field of view by as much as a factor of ten. Furthermore, examination of image statistics in near real time allows for the observing cadence to be increased or decreased depending upon the level of aurora or nightglow signal, allowing for significantly improved temporal sampling during period of increased emission intensities. Typical measurement errors of 5 to 10 ms-1 and 15 to 30 K for nightglow and 3 to 5 times better than this for aurora can be obtained with integration times as short as 30 seconds. This enhancement of the FPI instrumental sensitivity has made possible the deployment of relatively inexpensive FPI systems to locations where the data acquired have yielded new insights into upper atmospheric physics by measuring the climatology and seasonality of the thermosphere wind and temperature responses to atmospheric forcing functions such as pressure gradients, ion drag, and the Coriolis force. In addition, a new method achieving a mapping capability for upper atmospheric dynamics using data from a network of FPI observatories has been developed that can generate estimates of the thermospheric wind's divergence and vorticity, providing new insights into the complexities of thermosphere dynamics. Finally, it has become possible to explore the thermosphere-ionosphere coupling relationship by simultaneously measuring ionospheric drift and ion temperature with the same FPI instrument that also measures the thermosphere neutral wind and temperature. This capability is achieved by observing the metastable 732-nm emission of the O+(2P) state in aurora or twilight airglow, which is too weak to produce useful measurements with previous FPI designs.

9.c.7 16:47 - 17:00: M. J. Taylor: An Advanced Mesospheric Temperature Mapper for Novel Mesospheric Research

- Utah State University

Co-author(s): P.-D. Pautet[1], Y. Zhao[1], W.R. Pendleton, Jr.[1], R. Esplin[2], D. McLain[2]
- [1] Utah State University, [2] Space Dynamics Laboratory, USU Research Foundation

The Advanced Mesospheric Temperature Mapper (AMTM) is a high-performance infrared (IR) digital imaging system that sequentially observes selected emission lines in the mesospheric OH (3,1) band ($\sim$1.55 μm) to determine band intensity and rotational temperature and their variability at the $\sim$87 km level. In this spectral range the OH emission lines are $\sim$70 times stronger that the OH (6,2) sub-micron band frequently used for "classical" CCD imaging systems. These data are used to create high-quality intensity and temperature maps of a broad spectrum of mesospheric gravity waves (with periods ranging from several minutes to many hours), with an exceptional spatial ($\sim$0.5 km) and temporal (typically 30 sec) resolution over a large 120° field of view. This instrument was designed and built at Utah State University especially for high-latitude research and quantitative wave measurements can be made even in the presence of strong (IBC III) aurora. Three AMTM's have been developed to date; two are currently operational at the ALOMAR Arctic lidar Observatory, in Northern Norway (69°N) and at Amundsen-Scott South Pole Station, Antarctica (90°S). The third AMTM was developed recently for operation on the NSF GV aircraft and obtained remarkable gravity wave data during the recent NSF DEEPWAVE program conducted from New Zealand, June-July, 2014. This presentation describes the AMTM instrument illustrating its capabilities for precision wave measurements at any latitudes, even under adverse observing conditions (full Moon and street lights). Example results will include high-resolution wintertime studies of continuous (24-hr) gravity wave activity and spectral evolution, dynamics of mesospheric mountain waves, new evidence of gravity wave "self acceleration", and "rare" gravity wave breaking and dissipation events.

17:15 - 19:00: Posters – Particles, Photons [Lobby]

Chair(s): T. Moore, G. Collinson, S. Christe, J. Davila

See Section 21.a for Particles Poster abstracts.

See Section 21.b for Photons Poster abstracts.

18:30 - 19:30: Science Instrument Hosted Payload Workshop [Center]

Contact: Gerald Thompson
A single space-flight can make all the difference between an instrument being ignored forever, versus reaching a high TRL-level and finding further applications on follow-on missions. Any instrument that does not have a very high TRL cannot be considered for an operational mission, for example. The challenge then for most of our instruments is having them included as a payload on a satellite and flown in space.

The purpose of this Workshop is to find opportunities for the community to fly their instruments in space, so that lessons can be learned, scientific data can be obtained, and instrument development can be accelerated. ASTRA, LLC is hosting this event and will be sharing information on various Hosted Payload opportunities (both LEO and GEO) that they are aware of through their relationships and experience with the SmallSat market launch providers.

For this first meeting we will focus on various categories of potential instruments that the community sees as desirable missions. By participating in this Workshop, you will have the unique opportunity to explore other "hosted payload" opportunities that are ground-based such as from ocean platforms, ships andor buoys.

Wednesday, April 22, 8:30 - 17:00

10 8:30 - 10:15: PLENARY – Fields (#2) [Auditorium]

Chair(s): B. Anderson, R. Pfaff

10.1 8:30 - 9:05, *Invited*: Robert Strangeway: Magnetic Field Measurements on Spinning Spacecraft

- UCLA

Co-author(s): Christopher T. Russell[1], Hannes Leinweber[1], David R. Pierce[2], Kathryn M. Rowe[1], David Leneman[1]
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The fluxgate magnetometer is an instrument that has been flown on spacecraft since the dawn of the space age. The usual implementation involves a feedback system that nulls the external field, allowing the magnetometer to operate in a regime that ensures linearity in response and stable gains and offsets. Although fluxgate magnetometers have been flown on 3-axis stabilized platforms, there are considerable benefits in being flown on a spinning spacecraft. Primarily because the magnetometer axes can be orthogonalized by comparing the magnetic field in the spin plane with that along the spin-axis, provided one of the axes is aligned within a few degrees of the spacecraft spin-axis. Absolute calibration of the fluxgate magnetometer can be done through comparisons with the Earth's magnetic field, for low altitude spacecraft, or through measurements of Alfvénic fluctuations in the solar wind, if the spacecraft apogee is high enough. In addition to reviewing the basic operation of a fluxgate magnetometer we will also discuss some recent advances in implementation. In particular, while the fluxgate sensor is an analog device, modern fluxgate magnetometers minimize the use of analog components in the electronics. Furthermore, the use of Field Programmable Gate Arrays (FPGAs) or Application Specific Integrated Circuits (ASICs) have reduced the reliance on Analog to Digital Converters (ADCs). This allows the magnetometer to provide much higher resolution data without sacrificing radiation tolerance. Finally, while the standard fluxgate design uses feedback to null the external field, we can also operate the fluxgate without feedback. This allows us to operate a suitably constructed fluxgate magnetometer as a gradiometer. This allows for better characterization of spacecraft fields, and may also be useful in other applications, such as sampling materials on a planetary surface.

10.2 9:05 - 9:40, *Invited*: Stuart Bale: Broadband electric field and waves measurements in the solar wind: The Solar Probe Plus/FIELDS

- University of California - Berkeley

High quality DC electric field measurements in low density plasmas require current biased double probes with a high degree of symmetry to the Sun. The current biasing technique drives the probe potential close to the local plasma potential and ensures a large impedance to the plasma. On the other hand, high quality AC/radio measurements require long antennas with minimal surface area, low stray capacitance, and very good noise performance. In this talk, I'll describe an instrument, for Solar Probe Plus (SPP), designed make electric field and waves measurements from DC to 20 MHz. The SPP/FIELDS instrument will have good sun-symmetry, avoid wake disturbances, and use current-biased probes to measure DC fields and waves. On the other hand, the probe design is optimized to be sensitive to electron quasi-thermal noise and solar radio emissions in the AC-coupled regime. A new preamp design treats signals from DC to 20 MHz and uses three separate signal chains to produce DC, 'waves', and radio frequency voltages.

10.3 9:40 - 10:15, *Invited*: Robert Ergun: Measurement of Three Dimensional Electric Fields in Space

- University of Colorado - Boulder

Advances in space plasma physics including reconnection, acceleration, and turbulence require understanding of non-ideal behavior, which has been shown to be ubiquitous in active regions and near boundary layers. Accurate, three-dimensional DC electric fields are essential to make progress in our understanding of these phenomenon. Since the very first DC electric field measurements were made, the accuracy of DC electric field instruments has improved steadily with each new effort. When viewed over decades, the improvement is quite dramatic. Measurement accuracies are bettering $\sim$1 mV/m in many plasma environments and parallel electric fields are now measured routinely. While many remaining challenges are spacecraft-related, including the spacecraft wake, asymmetric potential structures, and uneven surface properties, the spin-axis direction, which completes the vector electric field when combined with the spin-plane vector, remains the most challenging component of the vector DC electric field measurement. This paper discusses the design of the MMS electric field instrument, the challenges, and possible future improvements.

11 10:30 - 12:15: PLENARY – Photons (#2) [Auditorium]

Chair(s): J. Spann

11.1 10:30 - 11:22, *Invited*: Stephen Mende: Observing the magnetosphere through auroral imaging

- University of California - Berkeley

It had been widely held that the terrestrial aurora is a two dimensional screen on which the Earth's three dimensional magnetosphere is projected. Over the years it has been realized that there are fundamental limitations in observing magnetospheric processes through their auroral footprints. It has been shown that much of the electron aurora is produced in the auroral acceleration region at lower altitudes (<2Re) in the last step of processing the auroral particles. From FAST, IMAGE , Cluster and THEMIS data we can now distinguish between three fundamentally different types of auroral acceleration regions and the type of magnetosphere-ionosphere coupling that produces the aurora in each region. To improve our ability to image the magnetosphere the most urgent task is to gain a better understanding of the various auroral acceleration processes that produce the auroras in the three regions. Besides, understanding particle acceleration in space plasmas is a fundamental goal of space physics, it is a process operating in solar and astrophysical plasma regimes unreachable by in situ probing. From the three auroral acceleration regions, the inverted V type electron precipitation is distinguishable by mono-energetic electron spectra, of several keV in energy, and low number flux consistent with the source population in the plasma sheet. Currently our understanding of how these auroras relate to magnetospheric processes is vague, probably associated with convection sheer. Alfvénic type of electron auroras predominantly occur during substorms, are generated by energy carried by waves from the magnetosphere into the ionosphere, where it is converted into electron energy. These type of auroras are the most promising candidates for footprints of incoming Alfvén waves probably mapped to source regions of reconnection sites or magnetospheric dB/dt events. These auroras can be distinguished by their low average energy (<2 keV) and their very high particle fluxes consistent with their high density ionospheric electron source. There is great potential in separately imaging auroras generated only by the Alfvénic processes. Optical measuring techniques of electron energy use the atmosphere as a spectrometer, using the penetration altitude as a proxy for energy, from the local properties of the atmosphere such as composition, collisional quenching of long lifetime emitters, degree of O2 absorption in the UV or the local neutral temperature. Some ideas how to advance these techniques will be discussed. Protons are usually an order of magnitude more energetic therefore less affected by fields in the low altitude auroral acceleration region. Proton precipitation can be used as a direct mapping tool for regions of the magnetosphere with highly stretched closed field lines, the open-closed-field-line and the lower latitude isotropic boundary. Using the observation techniques demonstrated on IMAGE from a stabilized non-rotating satellite proton measurements could be made with 24 times the sensitivity. This advantage could be used to measure the energy of the precipitated proton as well as the energy flux. Satellite based spectral imaging of the aurora will remain a significant tool in understanding space plasma physics in the magnetosphere.

11.2 11:22 - 12:15, *Invited*: Larry Paxton: UV Measurement Techniques

- John Hopkins University APL

The ultraviolet spectral signatures of the Earth (and other planetary atmospheres) provide key measures of the composition, energetics, chemistry and dynamics of the upper atmosphere. UV measurements have proven to be very useful in exploring the upper atmosphere because they reflect energetic (i.e. non-thermal excitation) processes. The ultraviolet is usually defined as that part of the spectrum with wavelengths shorter than about 300nm. There are three other useful regions for further defining the UV: the near UV or NUV (about 300 to 400nm), the middle UV or MUV (200 to 300 nm), the far ultraviolet (100 to 200 nm) and the extreme UV about 10 to 100nm). In this talk we describe UV technology in general with an emphasis on FUV technology and applications. This reflects the current (TIMED/GUVI and DMSP/SSUSI) and near-term sensors (ICON/FUV and GOLD) and missions on the horizon such as DYNAMIC. Sensor design issues and measurements will be described as well as basic design principles and challenges.

12 13:15 - 15:00: PARALLEL SESSIONS – Ground, Particles, Fields

12.a Ground – Solar [North]

Chair(s): S. Christe

12.a.1 13:15 - 13:35, *Invited*: Joan Burkepile: What's new at the Mauna Loa Solar Observatory

- NCAR High Altitude Observatory

Co-author(s): Alfred deWijn, Steve Tomczyk
- NCAR High Altitude Observatory

The Mauna Loa Solar Observatory (MLSO), operated by the National Center for Atmospheric Research High Altitude Observatory (HAO), currently operates 3 instruments to study solar dynamics and evolution: The COSMO K-Coronagraph, installed in late 2013, which observes the polarization brightness of the solar corona from 1.05 to 3 solar radii at 15 second cadence; the Coronal Multi-Channel Polarimeter (CoMP) which acquires full stokes polarimeteric observations of the low corona in the Fe XIII emission lines at 1074.7 nm and 1079.8 nm and the He-I line at 1083.0 nm; and the Precision Solar Photometric Telescope (PSPT) which produces high precision photometric images of the solar photosphere and chromosphere. These instruments provide unique information about coronal magnetic fields, Coronal Mass Ejection (CMEs) formation and early acceleration and the contribution of sunspots, faculae, plage and quiet Sun network to solar irradiance variability.

Over the next year HAO will deploy the Chromospheric Magnetometer (ChroMag) to MLSO. ChroMag will provide full Stokes polarimetery of the chromosphere and photosphere in a variety of wavelengths between 530.3 and 1083.0 nm at high time cadence. ChroMag observations will monitor magnetic and thermodynamic conditions of the chromosphere that lead to solar activity and advance our understanding of energy storage in the chromosphere and its transport into the corona and solar wind.

HAO is also upgrading the CoMP instrument to obtain a wider range of emission lines (530.3 to 1083.0 nm) with an improved field-of-view to better understand the dynamical changes in the coronal magnetic field that lead to CMEs and other forms of solar activity.

12.a.2 13:35 - 13:55, *Invited*: Steven Tomczyk: A Large Coronagraph for Solar Coronal Magnetic Field Studies

- NCAR High Altitude Observatory

Measurements of solar coronal magnetic fields are required to advance our understanding of the processes responsible for coronal heating, coronal dynamics, and the generation of space weather that have severe societal consequences. Recent advances have shown that observation of the Zeeman effect in IR coronal emission lines holds promise for the measurement of coronal magnetic fields. These measurements are very difficult due to the low photon flux of the corona and the small magnetic fields present there. We are proposing to build a 1.5-m aperture refracting coronagraph to routinely measure the strength and direction of magnetic fields in the solar corona, as part of the Coronal Solar Magnetism Observatory (COSMO). The science drivers of a coronal magnetograph will be presented along with derived instrument requirements. A coronagraph design that meets these requirements will be presented along with engineering studies that demonstrate the feasibility of constructing this coronagraph.

12.a.3 13:55 - 14:08: Gelu Nita: Measurement of duration and signal to noise ratio of astronomical transients below the instrumental resolution limit using a Spectral Kurtosis spectrometer

- New Jersey Institute of Technology

Co-author(s): Dale Gary
- New Jersey Institute of Technology

Following our prior theoretical and instrumental work addressing the problem of automatic real-time radio frequency interference (RFI) detection and excision from astronomical signals, the wideband Spectral Kurtosis (SK) spectrometer design we proposed is currently being considered as an alternative to the traditional spectrometers when building the new generation of radio instruments. The unique characteristic of an SK spectrometer is that it accumulates both power and power-squared, which are then used to compute an SK statistical estimator proven to be very effective in detecting and excising certain types of RFI signals, especially RFI transients below the instrumental resolution limit. What was considered until now a potential drawback of an SK spectrometer is that it cannot discriminate non-RFI transient signals of interest from man-made RFI when they occur on a timescale shorter than the instrumental integration time. In this study, however, we show that such built-in sensitivity of an SK spectrometer to transient signals of interest, rather than being a drawback, is a unique capability that can be used to both detect them and to quantitatively estimate their effective durations and signal-to-noise ratios. We demonstrate this novel experimental technique by analyzing a segment of data recorded by the Expanded Owens Valley Solar Array (EOVSA) Subsystem Testbed (EST) during a solar radio burst displaying microwave spikes for which we estimate individual durations shorter than the 20ms time resolution of the instrument.

This work was supported by NSF grants AGS-1250374 and AGS-1262772, and NASA grant NNX14AC87G to New Jersey Institute of Technology.

12.a.4 14:08 - 14:21: Valeriy Popov: 2D Linear Polarimetry in Prominences

- Lomonosov Moscow State University

Co-author(s): Iraida Kim
- Lomonosov Moscow State University

So far, both linear and circular polarization measurements in prominences are rare. Problems of near-limb "weak" magnetic field measurements are well known for practitioners. An approach for 2D linear polarimetry in prominences with actual accuracies <2% and <2 degrees is briefly described. The developed analysis technique of I, Q, U Stokes parameters is aimed at obtaining the 2D distributions of the linear polarization degree, the polarization angle and the sign of the angle which we refer the polarization images similar to conventional ones (2D distributions of I Stokes parameter). The key components are Stokes vector presentation of the light, reduction of random error by the use of "statistics", reduction of systematic errors by the solution of the overdetermined system of 24 equations by least squares. Broad-band filter eclipse linear polarimetry in prominences were used to test the approach. Polarization images of the sign of the angle of H-alpha prominences exclude the direct classification of these objects as prominences with either normal or inverse polarity and demonstrate opportunities for non-eclipse coronagraphic filter linear polarimetry as well. Parameters of feeding optics, analyzers and narrow band filters are estimated.

12.a.5 14:21 - 14:34: Enrico Landi: Coronal Plasma Diagnostics from COSMO

- University of Michigan

Co-author(s): Steve Tomczyk, Shadia Habbal
- NCAR High Altitude Observatory, University of Hawaii

In this talk I will discuss the diagnostic potential of observations of visible spectral lines formed in the extended solar corona that can be obtained with a large-scale coronograph observing from the ground, such as the COSMO large-aperture coronograph being currently under study. COSMO is aimed at measuring the magnetic field of the Sun from the chromosphere to the extended corona. In this talk I will focus on all other possible diagnostic applications of a COSMO-like coronograph, to measure the physical parameters of the extended corona, to understand solar wind origin and acceleration, to determine the evolution of Coronal Mass Ejections during onset, and to quantify the 3D evolution of the global solar corona. I will first review the mechanisms of formation of spectral line intensities, I will then illustrate their diagnostic applications, and show some results from recent eclipse observations. I will also review the spectral lines that are most likely to be observed in the extended solar corona.

12.a.6 14:34 - 14:54, *Invited*: Kevin Reardon: Fabry-Perot-based imaging spectrographs for solar observations

- National Solar Observatory

In the last decade, Fabry-Perot Interferometers (FPI) have emerged as a key technology for studies of the highly dynamic, highly structured solar atmosphere. I will discuss the characteristics of the Sun that have driven the need for spectrally resolved imaging of the photosphere and chromosphere for many types of investigations. The desire for high spectral and spatial fidelity and coverage result in increasingly stringent requirements on the quality and performance of the FPI used in solar physics. I will discuss the challenges being faced in the development of interferometers for new instruments and describe some of the new scientific advances that may be enabled with this technology.

12.b Particles – Energetic Neutral Atoms [Center]

Chair(s): S. Kanekal

12.b.1 13:15 - 13:35, *Invited*: Stas Barabash: Imaging of Space Plasmas with Energetic Neutral Atoms

- Swedish Institute of Space Physics

We begin with a brief review of the energetic neutral atom (ENA) production in space plasmas via charge –exchange and backscattering from solid surfaces and formulate the main science objectives for ENA imaging of various space plasma populations. We then describe and illustrate with examples of accomplished instruments two main measurement techniques, conversion to ions on surfaces and ENA interaction with foils, which are proven to work for imaging of ENAs for energies below and above a few 100s eV respectively. The main focus of the talk will be given to an overview of the achieved performances of ENA imagers and new frontiers. The main goal for the coming ENA instrument development is to achieve a degree or even sub-degree angular resolution. We identify the main instrumental issues and potential solutions for this outstanding experimental problem.

12.b.2 13:35 - 13:55, *Invited*: Donald Mitchell: Energetic Particle Imaging – the Jovian Energetic Neutrals and Ions imager on JUICE

- John Hopkins University APL

Co-author(s): Pontus Brandt, Joseph Westlake, Steven Jaskulek, Bruce Andrewsk
- John Hopkins University APL

Imaging of energetic particles has played an important role in several NASA missions, most notably the IMAGE mission, the Cassini mission (joint with ESA), and the IBEX mission. This talk will not review the instrumentation on those missions, but will instead focus on the advances we have included in the basic design of IMAGE HENA and Cassini MIMI INCA for future missions. The development effort has included both internal IR&D and NASA instrument development support, and now we are refining and developing specific features to meet the requirements of the NASA supported Jovian Energetic Neutrals and Ions (JENI) instrument to be flown on the ESA JUICE mission to Jupiter, Ganymede, and Europa.

The primary new developments involve reducing the entrance Start foil thickness from the 10 to 15 micrograms/cm^2 used in INCA and HENA to ∼1-2 micrograms/cm^2. This allows higher angular resolution imaging (∼2 degrees FWHM over much of the energy range) and extension of the technique to lower energy than the minimum resolution and energy of ∼6 degrees and ∼10 keV for HENA and INCA. Additionally, timing coincidence techniques permit the new design to achieve a useful signal to noise ratio (SNR) in the high penetrating background radiation environment in Jupiter's magnetosphere. These same techniques also allow us to image ENA while largely eliminating backgrounds from UV light without relying on the thin entrance foils as UV filters. JENI also includes a line of pixels of solid state detectors (SSD) over a strip of its back plane, which allows us to make well discriminated composition measurements for particle energies above the thresholds of the SSDs.

Although originally conceived as ENA imagers, these same instruments make excellent ion instruments as well. With the voltage on the charged particle rejection plates in the entrance collimator set to zero, the high angular resolution provides detailed pitch angle distributions of energetic ions, including ion composition above the SSD thresholds. Likewise, energetic electrons can also be measured, though with less angular resolution. JENI includes a variable aperture mechanism to stop down the entrance slit when high particle intensities might otherwise drive the sensor into saturation, a critical component for the Jovian environment.

12.b.3 13:55 - 14:08: Martin Wieser: The Jovian Neutrals Analyzer, a energetic neutral atom sensor of the Particle Environment Package for JUICE

- Swedish Institute of Space Physics

Co-author(s): Stas Barabash, Asamura Kazushi, Peter Wurz
- Swedish Institute of Space Physics, Institute of Space and Astronautical Science, University of Bern

The Jovian Neutrals Analyzer (JNA) is one of six sensor of the Particle Environment Package (PEP) on the JUICE mission. JNA is based on the successful energetic neutral atom (ENA) camera flown on the Indian Chandrayaan-1 mission to the moon and the ENA camera on board of Mercury Magnetospheric

Orbiter of the BepiColombo mission.

JNA measures energetic neutral atoms (ENAs) energy, mass and angular resolved in the energy range from 10eV to 3.3keV with an angular resolution of 7° x 14.5°. In the Jovian system, JNA will image backscattered and sputtered neutral atoms from the Jovian moons and image the Io plasma torus.

JNA uses surface interaction to convert the incident neutral atoms to a positive charge state prior energy analysis in an wave shaped electrostatic energy filter. Mass resolution is provided by a time of flight section also employing a surface interaction to generate the time-of-flight start signal. The sensor is complemented by an entrance collimator that also serves as charges particle rejection system. We present the instrument concept in detail and evaluate measured and predicted performance.

The Jovian environment is challenging due to high levels of penetrating radiation producing unwanted instrument backgrounds. We review the current state of radiation mitigation measures employed in JNA and compare to required scientific performance.

12.b.4 14:08 - 14:21: Joseph Westlake: High Angular and Energy Resolution Low-Energy Neutral Imager (LENI)

- John Hopkins University APL

Co-author(s): Donald Mitchell, Pontus Brandt
- John Hopkins University APL

To achieve breakthroughs in the areas of heliospheric and magnetospheric energetic neutral atom (ENA) imaging a new class of instruments is required. We present a high angular resolution ENA instrument concept aimed at the suprathermal plasma populations with energies between 0.5 and 20 keV. This instrument is ideal for understanding the spatial and temporal structure of the heliospheric boundary recently revealed by the Interstellar Boundary Explorer instrumentation and the Cassini INCA ENA camera. It is also possible to utilize this instrument to characterize magnetospheric ENA emissions from low-altitude ENA emissions produced by precipitation of magnetospheric ions, or ENAs produced at the subsolar magnetopause where solar wind protons are neutralized by charge exchange, or portions of the ring-current region.

We present a novel technique utilizing ultra-thin carbon foils, 2D collimation, and a novel electron optical design to produce high-angular resolution ($\leq$4°) and high-sensitivity ($\geq$ 10-3 cm2 sr/pixel) ENA imaging in the 0.5-20 keV energy range.

12.b.5 14:21 - 14:34: Jason McLain: Low-Energy Energetic Neutral Atom Imagers: MINI-ME (Miniature Imager for Neutral Ionospheric atoms and Magnetospheric Electrons) and MILENA (Miniaturized Imager for Low Energy Neutral Atoms)

- University of Maryland

Co-author(s): John Keller[1], Dennis Chornay[2], Doug Rowland[1], Michael Collier[1]
- [1] NASA GSFC, [2] University of Maryland

Three low energy energetic neutral atom imagers, FASTSAT's MINI-ME and VISIONS's two MILENAs have been used to study ion outflow during auroral substorms. ENA's with energies ranging from 10 to 3000 eV were observed. The imagers are high-energy resolution top-hat analyzers that use a venetian-blind assembly to convert energetic neutrals to negative ions which are then energy analyzed via an electrostatic toroidal deflection analyzer (ESA). The instrument consists of a sensor with cylindrical envelope (16.5 cm diameter × 12.5 cm high) with an electronics box 14 × 14 × 5 cm. The mass, including deployer, is 4 kg, and required 12 W at 28 V. The top-hat design enables a 360° field-of-view with spatial resolution, 10° × 60°, tilt by azimuth extent respectively. The converted ENAs are detected by six 25 mm circular MCP stacks. Unwanted ions and electrons are discriminated against entering the ESA via an electrostatic charge particle deflection system. ENA energy spectra were acquired by stepping the ESA voltage, where $\Delta E/E = 0.1$. All three imagers performed exceptionally well. The MILENAs proved in their very short 15 minute sub-orbital flight that the top-hat design achieves significant ENA count rates (∼1000 counts/s) in the auroral region even during modest activity levels (Kp = 1∼2), and MINI-ME collected 2 years of ENA data (measuring ENA intensities up to 5000 counts/s) in orbit before the spacecraft was turned off in 2012.

12.b.6 14:34 - 14:47: Keiichi Ogasawara: Comparison of next-generation solid-state detectors for measuring plasma and energetic particles in space

- Southwest Research Institute

Co-author(s): Frederic Allegrini, Thomas W. Broiles, Maher A. Dayeh, Mihir I. Desai, Robert W. Ebert , Stefano A. Livi, David J. McComas
- Southwest Research Institute

The performance of silicon avalanche photodiodes (APDs) and single crystal chemical vapor deposit diamond detectors (DDs) are reviewed in comparison with conventional silicon based solid-state detectors (SSDs), which are used extensively to measure plasma and energetic particles in space. As charged particles pass through the reversely biased p-n junction of SSDs, they cause a detectable amount of ionization carriers. Since the number of these carriers is proportional to the deposited energy by the incident particles, their energy can be estimated based on their species individually. The technological difficulties related to SSDs include the high leakage currents and high thermal noise at room temperature, the rapid degradation from radiation doses (<10^{12} to 10^{13} protons/cm^2), and the slow signal rise time (10s to 100s ns), the latter limiting their ability to be applied for timing analysis of ions in size-limited space instrumentation requiring $<$ 1 ns resolution. Although the radiation tolerance is similar to SSDs, APDs have several improvements; the lower energy threshold (<0.9 keV/Si), and the higher energy resolution (<0.7 keV FWHM at room temperature) with linear response due to a strong electric field causing signal amplification inside the detector. Therefore APDs can be applied to detect lower-energy particles thereby covering a larger portion of the energy spectrum compared to SSDs. Further, APD's strong internal electric field also gives them a sub-nanosecond response time by the charge mobility saturation, which allows them to make precise timing measurements of ions. In contrast, DDs offer a high radiation tolerance and very low leakage currents due to a wider band gap than silicon. Although the low energy threshold energy and the energy resolution are equivalent to SSDs, DDs can tolerate up to 3x10^{15} protons/cm^2 of ionizing radiation doses. DDs have several additional improvements; the operation at higher temperatures (>150 °C), the immunity to light (>226 nm), and the capability of timing analysis due to higher intrinsic carrier mobility. In this presentation, we discuss the advantages of these novel detectors along with our recent laboratory measurements, and show some of the potential applications for future space plasma instruments.

12.b.7 14:47 - 15:00: Mark Wiedenbeck: Recent Advances in the Design of Silicon Detector Telescopes for Energetic Particle Measurements in Space

- *NASA JPL & CalTech*

Co-author(s): J.A. Burnham[1], E.R. Christian[2], W.R. Cook[1], A.C. Cummings[1], A.J. Davis[1], B. Kecman[1], J. Klemic[1], A.W. Labrador[1], R.A. Leske[1], R.A. Mewaldt[1], J.S. Rankin[1], S. Shuman[2], E.C. Stone[1], T.T. von Rosenvinge[2]
- [1]*CalTech,* [2]*NASA GSFC*

For more than four decades silicon solid-state detector telescopes employing the dE/dx versus total-energy technique have been widely used for measuring particles with energies ranging from a few MeV/nucleon to nearly a GeV/nucleon. The capabilities of this type of instrument have steadily progressed as a result of the increasing sophistication of silicon detectors and associated signal processing electronics. Recent advances are being incorporated in the high-energy energetic-particles instrument (EPI-Hi) being developed as part of the ISIS (Integrated Science Investigation of the Sun) instrument suite for NASA'S Solar Probe Plus mission. These include: 1) very thin, uniform, position-sensitive ion-implanted silicon detectors; 2) rad-hard front-end electronics based on a custom ASIC having a very broad dynamic range; and 3) dynamically adaptable geometrical factors that allow measurements over a wide range of particle intensities. We will describe the instrument's design, its measurement capabilities, and the developments that made it possible. We will also show results from a variety of tests that have been carried out.

12.c Fields – DC Electric Fields [South]

Chair(s): H. Laasko, D. Rowland

12.c.1 13:15 - 13:35, *Invited*: Robert Pfaff: Electric Field Double Probe Experiments on Non-Spinning Satellites in Low Earth Orbit

- *NASA GSFC*

Co-author(s): Doug Rowland, Henry Freudenreich
- *NASA GSFC*

The performance and expectations of vector double probe electric field experiments on non-spinning spacecraft in low earth orbit are reviewed. Non-spinning satellites are often preferred for low earth orbit observations of the Geospace environment, particularly where ram-directed sensors require non-spinning platforms to continuously observe detailed properties of the ionized and neutral gases. Such configurations also enable nadir-pointing instruments as well as very accurate star trackers. Three-axis double probe experiments permit detailed, instantaneous measurements of the DC and AC electric field vector in which each orthogonal component gathers data using identical double probe detectors. Such double probes have included exposed cylindrical sensors (e.g., 1 m long) at the ends of insulated booms (e.g., Dynamics Explorer-2) whereas others have included small spherical sensors at the end of booms which are fed by wires to accommodate the signal as well as power for pre-amps embedded in the spheres (e.g., DEMETER and C/NOFS). Because there is no vehicle spin, the third electric field component that is typically oriented along the spin axis of spinning satellites need not be shortened to accommodate moment of inertia constraints imposed by spinning satellites with long wire booms in the spin plane. Boomlengths on the Dynamics Explorer-2 and C/NOFS satellites have extended the sensors approximately 20 m tip-to-tip in three orthogonal directions. Such boomlengths are sufficient to extend the sensors beyond the wake and sheath of the central spacecraft and permit high quality data of the geophysical electric fields over a wide range of plasma density, temperature, and composition. The vector measurements may be gathered at high temporal and spatial cadences, without the need to filter large signal contributions at the spin frequency, where important features of irregularity spectra and low frequency plasma waves may reside. Drawbacks of this geometry and satellite configuration include the difficulty of discerning the DC offsets along each component, the requirement of maintaining precise knowledge of the sensor positions at the end of the booms (e.g., $<$ 1 deg accuracy), and the general challenge of deploying stiff, thermally stable, lightweight booms to sufficiently long distances. Using data from the Vector Electric Field Investigation (VEFI) on the C/NOFS satellite, we demonstrate the feasibility of routine determination of the DC offsets on all three orthogonal axes, using occasional Òspin testsÓ to verify the offsets on two axes. We also demonstrate how the knowledge of the sphere positions, when mounted on thermally stable booms, may be ascertained to better than 1.0 degree of accuracy. Finally, we include a discussion of observations of slowly varying offsets and anomalous electric fields that sometimes appear in the C/NOFS electric field data set. Such anomalous electric fields appear, in general, to be organized by the vehicle velocity, possibly due to charging effects on insulator surfaces situated near the spherical electrodes.

12.c.2 13:35 - 13:55, *Invited*: Per-Arne Lindqvist: Spherical double probe electric field measurements on Viking, Freja, Astrid-2, Cluster and MMS

- *KTH Royal Institute of Technology*

Co-author(s): Göran Marklund[1], Anders Eriksson[1], Yuri Khotyaintsev[2]

- [1]*KTH Royal Institute of Technology,* [2]*Swedish Institute of Space Physics*

Spherical probes on radially extended wire booms for measuring electric fields have been flown on numerous satellites in the magnetoshpere and solar wind since the late 1970's. The technique is simple in principle but presents a number of challenges in practice. Electron photoemission from the probes needs active compensation by a bias current in order to keep the probes near the ambient plasma potential. Various asymmetries around the spacecraft may cause variations in the local plasma potential which affect the electric field measurements. These effects are sometimes possible to compensate for in orbit, and in other cases special treatment is needed in the ground data analysis. Instruments are described and examples of data are given from the Swedish small satellites Viking, Freja, and Astrid-2, as well as the large ESA and NASA missions Cluster and MMS, where the KTH and IRFU groups are responsible for the spin plane electric field instruments, covering a wide range of plasma conditions at altitudes from 600 km to 23 Earth Radii.

12.c.3 13:55 - 14:10: Harri Laakso: Comparison of DC Electric Field Measurement Techniques

- *ESA*

It is a major challenge to measure the DC electric field accurately in tenuous plasma regions, e.g. in the plasma sheet where the density often drops below 1/cc. The Cluster spacecraft carry five different experiments that can provide information about DC electric fields: (1) double probe antenna (EFW), (2) electron drift meter (EDI), (3) electron spectrometer (PEACE), and (4) two ion spectrometers (CIS-HIA, CIS-CODIF). Each technique is very different and has its own merits and limitations; note that only rarely all five measurements are available at the same time. Therefore it is important to compare all available measurements before making a judgement on the DC electric field and its variation. Although the full-resolution measurements have been calibrated to the best knowledge in the Cluster data archive, they can still contain various systematic and sporadic errors. However, when two experiments show the same electric field variation, it is quite likely that this is the right field because the techniques are so different. In this presentation we present several cases for the magnetopause and plasma sheet regions and investigate how different measurement techniques agree or disagree. We investigate cases where the field remains constant and where it varies rapidly.

12.c.4 14:10 - 14:25: Marcin Pilinski: An Evolution of CubeSat Based E-field Instrumentation

- ASTRA LLC.

Co-author(s): Geoff Crowley[1], Chad Fish[1], Charles Swenson[2]
- [1]*ASTRA LLC.,* [2]*Utah State University*

There is currently a need for inexpensive and robust space-weather monitoring instruments that can fill upcoming gaps in the Nation's ability to monitor critical space weather parameters and meet requirements for specification and forecasting. Foremost among the parameters that must be measured are electric fields, since they drive the ionospheric behavior at both high and low latitudes, and because there are relatively few ground-based measurements. In the future, we envisage a constellation of such instruments flying on CubeSats that will provide global coverage of the electric field and its variability.

Major strides have been taken in recent years towards the development of CubeSat instruments that will be required in the near future. The DICE (Dynamic Ionosphere CubeSat Experiment) was a step in this evolution: it was an ambitious program funded by NSF with two identical 1.5U CubeSats, each carrying three space weather instruments: (1) double probe instruments to measure AC and DC electric fields; (2) Langmuir probes to measure ionospheric electron density, and; (3) a magnetometer to measure field-aligned currents. While the DICE mission resulted in many successes, attitude control anomalies encountered in orbit prevented the 5-meter electric field booms from deploying. However, the DICE team has compiled important lessons-learned in troubleshooting these anomalies. These lessons are now being implemented into our next-generation design called Double-probe Instrumentation for Measuring Electric-fields (DIME). DIME improvements include modifications of the cable spool and spool-control. Note that both the CubeSat and the mission are being called DIME. Furthermore, because of the close integration of the CubeSat bus and instrument, we refer to the satellite as a SensorSat. The DIME SensorSat will be capable of deploying flexible electric field booms up to a distance of 10-m tip-to-tip. The satellite will measure AC and DC electric fields, together with ion densities, and magnetic fields to characterize the performance of the sensor in different plasma environments.

In this presentation, we describe the DICE Electric Field Instruments and CubeSats, review the challenges and lessons learned from the DICE mission, describe the DIME SensorSat, showing how the various challenges are being addressed for DIME, and demonstrating how the new systems will meet its measurement requirements. We will also show how the CubeSat E-field design evolution is continuing with new instruments on the Auroral Spatial Structures Probe and the development of a new version of the DIME instrument capable of achieving deployment lengths of 50 meters.

12.c.5 14:25 - 14:40: Douglas Rowland: A Three-Axis Double-Probe Electric Field Instrument for Small Satellites

- NASA GSFC

Co-author(s): Robert Pfaff[1], Jeffrey Klenzing[1], Christopher Cully[2], Larry Kepko[1]
- [1]*NASA GSFC,* [2]*University of Calgary*

Ionospheric electrodynamics measurements can benefit from the increasing availability of Cubesats and other small satellites. Two critical aspects of missions designed to study the combined ionosphere-thermosphere system create the need for a new type of electrodynamics instrument package: 1) The need to simultaneously measure gas and plasma properties often requires a three-axis stabilized platform with ram-facing apertures; and 2) spacecraft in high-inclination low earth orbits experience a large range of angles between the velocity vector and magnetic field vector. Given these realities, the development of an instrument that can measure the complete vector electric field with three identical, orthogonal double probe detectors on a three-axis-stabilized small spacecraft is a necessity.

We present the design of such an instrument that utilizes six orthogonal "rigid" booms, with spherical sensors, deployed to a length of 2 meters each (from the central 6U Cubesat which measures 10 x 20 x 30 cm), providing 4 meter tip-to-tip measurement baselines. This instrument incorporates onboard wave processing and burst memory, and is optimized for measurements at high latitudes (poleward of 55 degrees) where the electric fields are large. The main aspects of the experiment design that require technology development are: 1) The boom systems and low-power instrument electronics; 2) miniaturized star trackers for accurate attitude determination and VxB subtraction; and 3) an electrostatically clean spacecraft exterior, similar to those developed for larger spacecraft, and including covers for the solar array interconnects and an ITO coating for surface conductivity. This instrument is currently in development at NASA GSFC, along with two other instruments that can be accommodated in a tightly integrated electronics package: a 3-axis miniaturized fluxgate magnetometer and an advanced Langmuir Probe. All three instruments fit together to provide a combined fields and thermal plasma measurement package which will provide accurate, inexpensive measurements of ionospheric electrodynamics from a three-axis stabilized small spacecraft.

14:40 - 15:00: Discussion

13 15:15 - 17:00*: PARALLEL SESSIONS – Ground, Particles, Photons* (- 17:30)

13.a Ground – Arrays [North]

Chair(s): P. Erickson

13.a.1 15:15 - 15:35, *Invited*: Anthea Coster: Radio Observation Techniques: GNSS and Ionosondes

- MIT Haystack Observatory

Co-author(s): Juha Vierinen
- MIT Haystack Observatory

This talk focuses on the future potential of two different ground-based radio observation techniques: ionosondes and global navigation satellite systems (GNSS). Although both of these techniques are based on radio, they measure different attributes of the ionosphere. Ionosonde technology was invented in 1925 by Breit and Tuve, and is based on the ionospheric reflection of high frequency (HF) radio waves. The basic components of an ionosonde consist of: an HF transmitter, which sweeps through though all or part of the HF frequency range (1-20 Mhz); an HF receiver; and an antenna with a suitable radiation pattern. These are combined with both digital control and data analysis. Ionosondes provide detailed information about the bottomside of the local ionosphere, and can measure ionospheric drifts and traveling ionospheric disturbances. GNSS receivers, on the other hand, estimate the total electron content (TEC) in the ionosphere by measuring differential delays between two or more L-band frequencies along the line of sight between the satellite and the receiver. The strength of ground based GNSS observations comes not so much from TEC measurements from a single receiver but rather from the combination of TEC measurements from a network of receivers. In 2000, the density of GPS (one type of GNSS) receivers across the continental United States increased to the point that data-driven regional maps of TEC could be constructed. These data-driven maps allowed TEC gradients, such as the narrow plumes of storm-enhanced density (SED), to be clearly observed over the course of a geomagnetic storm. Since then, GPS TEC maps have become recognized as one of the premier tools to monitor space weather events. The current number of available dual-frequency receivers across the globe has now increased to more than 3000 receivers.

In the near future, however, there will be a rapid increase in the number of GNSS signals available. Besides GPS, the European Union is building a system named GALILEO, which will consist of a 30-satellite constellation. The Russians have a system based on a 24-satellite constellation named GLONASS. The Chinese are developing a system called Beidou, which means "stars of the Big Dipper". The Beidou system will consist of 35 satellites. By 2023, there will be more than 160 GNSS satellites and 400 signals. Multi-constellation, multi-band GNSS will be a major enabler for space weather studies.

13.a.2 15:35 - 15:55, *Invited*: Alan Weatherwax: At the Cusp of Discovery: The Evolution and Importance of Ground-based Geospace Arrays

- Siena College

Co-author(s): Andrew Gerard
- New Jersey Institute of Technology

Intensive investigations of our planet's atmosphere, ionosphere and magnetosphere system, a region now collectively known as geospace, were ushered in during the International Geophysical Year (IGY) in 1957-58. Often considered a critical milestone in the study of Earth and its environment, the IGY was a global effort engaging scientists from numerous countries to address a wide range of fundamental science questions. Pioneering approaches were developed during this time to explore geospace, including high-altitude balloons, sounding rockets, small satellites Ð which enabled the discovery of the Van Allen radiation belts around Earth – and advanced ground-based observatories. Today, geospace research has matured to the level of being able to both describe and predict many fundamental particle and field interactions in geospace. Not surprisingly, however, some problems are simpler and easier to solve, while research into others only reveals increasing layers of complexity. This recognition drives increasingly complex research methods, including the evolution of more sophisticated instruments, arrays of instruments, and the need for worldwide suites of instruments. It is only with multipoint measurements at many locations on Earth and in space that one can hope to probe the relevant physics central to geospace, which occurs on a wide range of spatial and temporal scales, and involves nonlinear cross-coupling between regions previously treated as distinct. This talk will primarily focus on the evolution of highly coordinated ground-based arrays of magnetometers, radiometers, Fabry-Perot interferometers, and all-sky imagers, that are currently employed to probe geospace and the relevance of this region in understanding the functioning of planet Earth within the solar system, the understanding of numerous aspects of laboratory physics and astrophysics, and the understanding of the Sun's influence on Earth and technological systems deployed on our planet and in space.

13.a.3 15:55 - 16:08: Andrew Gerrard: The Automatic Geophysical Observatory (AGO) Program- Past, Present, and Future

- New Jersey Institute of Technology

Co-author(s): Alan Weatherwax
- Siena College

The Automatic Geophysical Observatories (AGOs) are a collection of remote, unmanned platforms for geophysical monitoring on the Antarctic plateau. These unmanned systems provide power and data telemetry to various instruments across the fields of geospace, seismology, glaciology, and tropospheric weather monitoring. Yet the AGOs are not yet operating to full capacity, and simple modifications over the next 2 years will further expand their capability to host instruments. As such, this paper reviews the AGO systems and provides information for those wishing to install instrumentation in the Antarctic deep field.

13.a.4 16:08 - 16:21: David Milling: The CARISMA Magnetometer Array: status and future plans

- University of Alberta, Canada

Co-author(s): Ian Mann, Andy Kale, David Miles
- University of Alberta

The CARISMA magnetometer array now operates 3-component fluxgate magnetometers at 27 sites, making measurements of the earth's magnetic field at 8 samples per second cadence and a resolution of 25 pT. Eight of these sites are also equipped with sensitive induction coil magnetometers with a bandwidth of 0.001 to 30 Hz. The CARISMA site at Back, Manitoba, has been operated as an autonomous solar powered station since 2011. The experience gained of operating this site is to be used in the design and deployment of 3 new sites in 2015, which will incorporate a Next Generation (NGEN) digital fluxgate magnetometer design developed at the University of Alberta. Here we provide an update on the status of CARISMA and plans for the next generation of autonomous deployments. We will also summarise the data products produced by this extensive array of instruments and which are openly available from www.carisma.ca.

13.a.5 16:21 - 16:34: Mario Bisi: Observations of Interplanetary Scintillation (IPS) and Faraday Rotation (FR) for Solar-Wind and Space-Weather Studies

- RAL Space - STFC Rutherford Appleton Laboratory

Co-author(s): Richard Fallows[1], Charlotte Sobey[1], Bernard Jackson[2], Elizabeth Jensen[2], Hsiu-Shan Yu[3], David Jackson[4], James Tappin[5]
- [1]ASTRON, [2]CASS-UCSD, [3]PSI, [4]CASS-UCSD, UK Met Office, [5]RAL Space - STFC Rutherford Appleton Laboratory

The technique of interplanetary scintillation (IPS) has been used for over half a century for heliospheric science, and in recent years, much progress has been made in using IPS in space-weather science and forecasting. The technique of Faraday rotation (FR) is typically an astrophysical technique that uses pulsars and extragalactic sources to study the Galactic magnetic field. However, recent progress has been made in investigating the solar wind using FR in the hopes of being able to remotely-sense Bz between the Sun and Earth. Here we provide an overview these techniques and their use and capabilities (and future potential) for solar-wind and space-weather studies.

13.a.6 16:34 - 16:47: Seebany Datta-Barua: A GNSS Receiver Array Instrument for Distributed Sensing of Ionospheric Irregularities

- *Illinois Institute of Technology*

Co-author(s): Gary S. Bust[1], Yang Su[2], Kshitija Deshpande[3], Daniel S. Miladinovich[2], Geoffrey Crowley[4]
- [1] *Johns Hopkins University APL,* [2] *Illinois Institute of Technology,* [3] *Virginia Tech,* [4] *Atmospheric and Space Technology Research Associates*

Constellations of Global Navigation Satellite Systems (GNSS) have greatly advanced measurement techniques for the physics of the geospace environment. Worldwide publicly available GNSS receivers number in the thousands, with high density in certain parts of the world (as little as a few kilometers spacing), enabled by low cost due to chipset manufacturing scalability. Since the Global Positioning System (GPS) became operational in the early 1990's, ground receivers have been used to study amplitude and phase scintillations due to the presence of intermediate scale ionospheric irregularities. Initial studies aimed to characterize the statistics of occurrence of scintillations, and the impact of scintillations upon GPS navigation and communications. In the last few years scientific studies have included relating GNSS scintillations to the occurrence of large scale geomagnetic storms, the formation of equatorial bubbles, high-latitude polar cap patches, and auroral arcs, with a goal of obtaining improved understanding of the structure of ionospheric irregularities, and the large scale processes that physically cause the irregularities.

Most of these studies were carried out for single receivers, or arrays of receivers separated by 100's of kilometers. However, in order to investigate in detail the two-dimensional (2D) small scale structuring of ionospheric irregularities, their altitude, their horizontal spatial extent, and their time evolution, a closely-clustered 2D array of GNSS scintillation receivers is required. Such arrays are spaced at the scale sizes comparable to the irregularities that produce scintillations at GNSS L-band frequencies, with spatial resolutions of less than a Fresnel scale (∼100-300 meters) out to a few kilometers. These 2D arrays act as a single spatially distributed instrument, designed to observe the spatial-temporal structuring of ionospheric intermediate scale irregularities. We have established one such spatially distributed instrument – an array of seven receivers, the Scintillation Auroral GPS Array (SAGA) at Poker Flat Research Range (PFRR), Alaska.

SAGA has been continuously operating at PFRR since December 2013, routinely collecting low-rate scintillation statistics (amplitude S4 and standard deviation of phase) as well as high-rate (50-100 Hz) amplitude and phase data on all GPS satellites in view. The measurements from this distributed array can be analyzed in conjunction in a variety of different ways, effectively as a single instrument, to probe the structure of intermediate scale irregularities and the physical phenomena that cause the structuring. We present results from SAGA using a suite of analysis and inversion methods and techniques to study the structuring of ionospheric irregularities. Some of the methods used include 2D elliptical correlation and drift velocity analysis of the data [Costa et al., 1988; 1997], Rytov weak scatter inverse theory [Yeh and Liu, 1982; Taylor, 1975], and propagation of 3D electromagnetic waves through random media [Deshpande et al., 2014]. These methods are used to estimate the structuring of ionospheric irregularities, and relate that structuring to the large-scale dynamics by combining the SAGA results with other instruments at PFRR such as all sky imagers, neutral wind arrays, and the Poker Flat Incoherent Scatter Radar.

13.a.7 16:47 - 17:00: Hyomin Kim: An autonomous adaptive low-power instrument platform (AAL-PIP) for remote high-latitude geospace data collection

- *Virginia Tech*

Co-author(s): C. Robert Clauer[1], Kshitija Deshpande[1], Zhonghua Xu[1], Daniel Weimer[1], Steve Musko[2], Aaron Ridley[2], Jahshan Bhatti[3], Gary Bust[4], Geoff Crowley[5], Chad Fish[5], Todd Humphreys[3], Marc Lessard[6], Randall Nealy[1]
- [1] *Virginia Tech,* [2] *University of Michigan,* [3] *The University of Texas - Austin,* [4] *Johns Hopkins University APL,* [5] *Atmospheric & Space Technology Research Associates,* [6] *University of New Hampshire*

We report on the development, testing and deployment of the next generation of autonomous adaptive low-power instrument platforms (AAL-PIP) for use in remote Antarctic locations. Specifically, we are in the process of deploying a dense chain on the east Antarctic plateau along the 40 degree magnetic meridian. These stations are magnetically conjugate to the west coast of Greenland and enable us to investigate solar wind - magnetosphere - ionosphere coupling simultaneously in both polar regions. The Antarctic stations on this chain are designed to operate unattended in remote locations for at least 5 years. They utilize solar power and batteries for power, two-way Iridium satellite communication for data acquisition and program/operation modification, support fluxgate and induction magnetometers as well as a dual-frequency GPS receiver and a high-frequency (HF) radio experiment. Size and weight constraints are considered to enable deployment by a small team using small aircraft. Considerable experience has been gained in the development and deployment of remote polar instrumentation that is reflected in the present generation of instrumentation discussed here. We discuss the design, technical characteristics, and operation results. This research is supported by the National Science Foundation through a Major Research Infrastructure (MRI) grant ATM-922979 and research grants ANT-0839858 and PLR-1243398.

13.b Particles – Energetic [Center]

Chair(s): M. Wieser

13.b.1 15:15 - 15:35, *Invited*: Joseph F. Fennell: Energetic Particle Sensors

- *The Aerospace Corporation*

Co-author(s): J. B. Blake, J. E. Mazur, P. T. O'Brien, M. D. Looper
- *ACSSAL*

We will present examples of the kinds of energetic electron and energetic proton measurements (>50 keV) needed to meet many of the goals of the "Solar and Space Physics" decadal survey. We will show some of the more recent techniques and modeling tools used to achieve such goals and discuss their capabilities and limitations. In all cases, the difficulty in making absolute energy and flux measurements will be reviewed and discussed. Some techniques used to obtain quality measurements deep in the inner magnetosphere where the combined presence of high-energy protons or Bremsstrahlung photons capable of penetrating sensor shielding occurs will be presented. This relates to the classic problem of making usable flux measurements of lower energy particles when high backgrounds are present. Finally, we will discuss the use of targeted sensors to monitor the energetic space particle environment and support satellite anomaly analyses.

13.b.2 15:35 - 15:55, *Invited*: Shri Kanekal: Inter-calibration of energetic electrons and proton measurements by MagEIS, REPT and RPS instruments on board Van Allen Probes

- *NASA GSFC*

Co-author(s): D. N. Baker[1], J. B. Blake[2], S. Claudepierre[2], J. Fennell[2], V. Hoxie[1], A. Jaynes[1], A. Jones[3], X. Li[1], J. Mazur[2], P. O'Brien[2], G. Reeves[4], H. Spence[5]
- [1] *University of Colorado LASP,* [2] *The Aerospace Corporation,* [3] *Catholic University of America,* [4] *Los Alamos National Laboratory,* [5] *University of New Hampshire*

The Van Allen Probes mission comprising two identically instrumented spacecraft was successfully launched on 30 August 2012 into near equatorial orbit with an apogee of ~5.5 RE and a perigee of ~700 km. The Energetic particle Composition and Thermal Plasma Suite (ECT) comprises of two instruments that measure electrons and protons in the MeV regime,namely, Magnetic Electron Ion Spectrometer (MagEIS) and the Relativistic Electron Spectrometer (REPT). In addition the Relativistic Protons Spectrometer (RPS) measures very energetic protons of up to 2GeV. The measurement techniques span magnetic spectrometers, solid state particle telescope and Cerenkov radiation detection. There is sufficient overlap in the energy ranges covered by these individual instruments, thus enabling continuous spectral measurement over extended energy ranges beyond single instrument capabilities. The challenge is to cross-calibrate the instruments taking into account their disparate characteristics such as geometry factors, dead time corrections, background estimation etc. We report here on the current status of the cross calibrations and present results showing electron and proton spectra using more than two years of accumulated data.

13.b.3 15:55 - 16:08: George Ho: Measurements of Suprathermal Ion in the Heliosphere

- *Johns Hopkins University APL*

Co-author(s): Glenn Mason, Bruce Andrews
- *Johns Hopkins University APL*

Particles that have energies of a few times the solar wind plasma energy up to 100s of keV/q are called suprathermal particles. Recent studies have revealed that these particles may significantly contribute as seed particles for acceleration either close to the Sun in solar energetic particle (SEP) events, locally at 1 AU in energetic storm particle events, and outside 1 AU as ions accelerated in Corotating Interaction Regions. The origin of these suprathermal particles is largely unknown at this time. Possible sources include: 1) suprathermal tails of the fast and slow speed solar wind; 2) interstellar and "inner source" pick-up ions; and 3) remnant material from both gradual and impulsive SEP events. This suprathermal ion reservoir is not a fixed quantity, but is expected to vary in time and space. It is therefore important to make high-time and compositional measurements of this particle population in the inner heliosphere to better characterize its origins and contribution to particle acceleration processes. Here we describe the measurement requirements and new measurement techniques that will make significant contribution in this largely unexplored energy range.

13.b.4 16:08 - 16:21: Seth Claudepierre: A background correction algorithm for Van Allen Probes MagEIS electron flux measurements

- The Aerospace Corporation

Co-author(s): T. P. O'Brien[1], J. B. Blake[1], J. F. Fennell[1], J. L. Roeder[1], J. H. Clemmons[1], M. D. Looper[1], J. E. Mazur[1], T. M. Mulligan[1], H. E. Spence[2], G. D. Reeves[3], R. H. W. Friedel[3], M. G. Henderson[3], B. A. Larsen[3]
- [1] The Aerospace Corporation, [2] University of New Hampshire, [3] Los Alamos National Laboratory

We describe an automated computer algorithm designed to remove background contamination from the Van Allen Probes MagEIS electron flux measurements. We provide a description of the algorithm with illustrative examples from on-orbit data. We find two primary sources of background contamination in the MagEIS electron data: relativistic inner zone protons and bremsstrahlung X-rays generated by energetic electrons interacting with the spacecraft material. Bremsstrahlung X-rays primarily produce contamination in the lower energy MagEIS electron channels (∼30-500 keV) and in regions of geospace where multi-MeV electrons are present. Inner zone protons produce contamination in all MagEIS energy channels at roughly L<2.5. The background corrected MagEIS electron measurements will enable new scientific studies of the inner zone, as most earlier measurements suffer from unquantifiable and uncorrectable contamination in this harsh region of the near-Earth space environment. These background-corrected data will also be useful for spacecraft engineering purposes, providing ground truth for the inner zone electron environment and informing the next generation of spacecraft design models (e.g., AE9).

13.b.5 16:21 - 16:34: Birgit Ritter: Radiation testing for the Jovian environment: in the laboratory and on a CubeSat

- Swedish Institute of Space Physics

Co-author(s): Stas Barabash, Martin Wieser
- Swedish Institute of Space Physics

The harsh Jovian radiation environment is one of the main drivers for the design of instruments to be flown to Jupiter. The RAdiation Test EXperiment for JUICE (RATEX-J) presented here is a test setup for an anti-coincidence system for the Jovian plasma Dynamics and Composition analyzer (JDC). The anti-coincidence system is one of the several radiation mitigation techniques used in JDC. RATEX-J consists of two detector stacks, a multi channel plate (MCP) with an SSD and a ceramic channel electron multiplier (CCEM) with an SSD, front-end electronics, high voltage supply, and a simple data processing unit. This setup allows flexibility and mobility of the unit.

To simulate Jupiter's radiation environment and verify the performance of the detector system, is a complex experimental task. Two radiation tests will be conducted in order to test the efficiency of the anti-coincidence system and to test the detection efficiency of CCEMs and MCPs for penetrating radiation. RATEX-J will be irradiated with energetic electrons (MeV range) at accelerator facilities and is furthermore an accepted payload on a CubeSat to be flown on a polar sun-synchronize orbit. CubeSats provide a relatively easy-to-access platform to test small payloads in the natural radiation belt environment at Earth and are considered valuable for future instrument and subsystem testing, even for environments as harsh as Jovian.

JDC is one of six sensors within the Particle Environment Package (PEP) on ESA's JUICE mission to Jupiter in 2022. JDC measures 3D distribution functions of positive and negative ions (incl. electrons) in the energy range 1 eV per charge to 41 keV per charge.

13.b.6 16:34 - 16:47: Allison Jaynes: Using pulse heights from the Van Allen Probes' REPT instruments to fit the functional form of the relativistic energy spectrum in the inner magnetosphere

- University of Colorado - Boulder

Co-author(s): Richard Selesnick[1], Dan Baker[2], Shrikanth Kanekal[3], Xinlin Li[2]
- [1]AFRL, [2]University of Colorado - Boulder, [3]NASA GSFC

The REPT instrument, onboard NASA's Van Allen Probes mission, uses solid state detector theory and design to collect unprecedented measurements of energetic electrons and protons in the inner magnetosphere. The instrument has been making observations continually since September 2012, utilizing onboard logic equations to determine the energy and species of incoming particles. Beginning in October 2013, due to an increase in the spacecraft data rate, full pulse height analysis (PHA) events were able to be collected. Capture of full PHA signal allows for identification of finer energy resolution, and a look at the true spectrum of electrons in the outer radiation belt. In this study, we discuss the methods for determination of the full spectrum and characterize the functional form of the spectra over different intervals and Lshell ranges.

13.b.7 16:47 - 17:00: Frederic Allegrini: A comprehensive suprathermal ion sensor suite

- Southwest Research Institute

Co-author(s): Mihir I. Desai, Robert W. Ebert, Keiichi Ogasawara
- Southwest Research Institute

Ions with energies from a few times the solar wind plasma thermal energy up to 100s of keV/q are called suprathermal (ST) ions. ST ions are ubiquitous and comprise material from many sources that vary in time and space. ST ions constitute a key source of material for solar energetic particles and other higher energy interplanetary particle populations. Thus, measuring and quantifying the ST properties has been identified as one of the top priority science goals of the 2012 NRC Solar and Space Physics Decadal Survey. Measuring the energy spectra and composition (ionic charge and elemental) of ST ions in the heliosphere has proved to be rather difficult. This is because their energy region lies between that sampled by solar wind instruments, which require long integration times to acquire adequate statistics at these energies, and that by the energetic particle instruments, which typically do not extend down into the ST regime due to the low-energy thresholds (∼25-50 keV) of solid-state detectors.

We present two novel concepts that, when combined, measure ST ion with high time, mass, and charge state resolution to address the challenges. Both use innovative electrostatic analyzers (ESA) that essentially serve as spectrographs and simultaneously select ions over a broad range of energy-per-charge (E/q). These ESA designs require fewer voltage steps to cover the entire range, thus significantly increasing the product of the geometric factor times the duty cycle when compared with current instruments. We describe the results obtained with laboratory prototypes. We also present a list of potential options for the detector section.

13.c Photons – Detectors [South]

Chair(s): L. Glesener

13.c.1 15:15 - 15:45, *Invited*: Nikzad Shouleh: High Performance Solid State Detectors for Low Energy Neutral and Charged Particle Detection

- NASA JPL

Studying charged particles in the solar wind is an essential part of solar and space science as it helps the fundamental understanding of the solar effects of the Earth environment. Band structure engineering using molecular beam epitaxy including delta doping and superlattice doping have shown dramatic improvement in detector performance. These band structure engineering technologies have removed the dead layer of the silicon detectors. Delta-doping technology and Superlattice doping invented at JPL have been applied to charge-coupled devices (CCDs), CMOS, hybrid CMOS-PIN arrays, and avalanche photodiodes. The remarkable improvement enabled by delta doping and more recently by superlattice doping show in some cases over an order of magnitude improvement in low-energy detection threshold over conventional solid-state detectors. Because the typical low energy detection threshold of conventional solid-state detectors is much higher than the average energy of the solar wind particles, most instruments employ high voltage post-acceleration stage to achieve energies above the detection threshold of the conventional detectors (typically above 10-30 keV). This post-acceleration stage is massive, exposes the instrument to hazardous high voltages, and is therefore problematic both in terms of price and potential negative impact on scientific return.

We present the results of several studies using a suite of devices for detection of low energy particles. These devices include delta-doped charge-coupled device (CCD), delta doped hybrid CMOS arrays, delta doped and superlattice doped Electron Multiplying CCDs (EMCCDs), and superlattice doped Avalanche Photodiodes (APDs).

It should be noted that similar treatments are also very successful for extreme ultraviolet detection and have shown remarkable stability when exposed to high fluxes of deep ultraviolet or extreme ultraviolet photons. Results of deep measurements using a superlattice doped CMOS array are also briefly discussed.

Application of delta doped and superlattice doped detectors in future space missions will enable miniaturization of instruments.

13.c.2 15:45 - 16:00: Oswald Siegmund: Advances in Photon Counting Imaging Detectors

- University of California - Berkeley

Recent developments in photon counting detector systems have enabled considerable improvements in the performance, capability, size and durability of detectors for the soft X-ray through visible. We will present details of progress towards the development of several different detector systems for photon counting, imaging and timing in a range of applications.

The operational scheme of the photodetectors depends on the intended application, and varies widely. Recently advances have been made in back illuminated EMCCD detectors using MBE-delta doping and ALD-AR coatings. These can provide high QE in the FUV regime with stable response and improved out of band rejection. Other sensors based on microchannel plates have been used extensively in photon counting applications, and in these light is detected by a photocathode and amplified by an MCP pair or stack, then event positions and time are recorded with a conductive anode and electronics that calculates event centroids. New photocathodes with extended range and high QE are in development for these devices, including GaN with high QE (50%) in the FUV. A new type of borosilicate substrate MCP that are functionalized by atomic layer deposition (ALD) is also in development. These microchannel plates employing borosilicate micro-capillary arrays provide many performance characteristics typical of conventional MCPs, but have been made in sizes up to 20 cm, have low intrinsic background (0.06 events cm^2/s) and have very stable gain behavior over > 7 C cm^2 of charge extracted. They are high temperature compatible and have minimal outgassing, which benefits sealed tube production processes and should improve overall lifetimes. Furthermore spherical and cylindrical shapes to match focal planes are also possible. Tests with a 20 cm detector with a cross delay line readout have achieved $<100\mu$m FWHM imaging with MHz event rates, and tests with a 10 x 10cm detector with cross strip readout has achieved < 20 μm FWHM imaging with >5 MHz event rates with $\sim$15% deadtime. The latter also illustrates that improvements in readout systems and electronics have been considerable. Further advances are underway in reduction of the power, volume and increased performance of encoding electronics through custom ASIC design. We will discuss the details and implications of these novel detector implementations and their potential applications.

13.c.3 16:00 - 16:15: Shin-nosuke Ishikawa: Fine-pitch CdTe detector for the hard X-ray imaging and spectroscopy of the Sun with the FOXSI rocket experiement

- NAOJ & ISAS JAXA

Co-author(s): Shin Watanabe[1], Yusuke Uchida[1], Shin'ichiro Takeda[1], Tadayuki Takahashi[1], Shinya Saito[2], Lindsay Glesener[3], Juan Camilo Buitrago-Casas[3], Säm Krucker[3], Steven Christe[4]
- [1]ISAS/JAXA, [2]Rikkyo University, [3]University of California - Berkeley, [4]NASA GSFC

We have developed a fine-pitch hard X-ray (HXR) detector with cadmium telluride (CdTe) semiconductor for the imaging and spectroscopy with the second launch of the Focusing Optics Solar X-ray Imager (FOXSI) sounding rocket experiment. The past and current HXR instruments use non-focusing technics to obtain images of the Sun such as a modulation collimator, and sensitivity and dynamic range are limited because an image reconstruction procedure is necessary. FOXSI is a rocket mission to perform high sensitivity HXR observations at 4-15 keV range using a new technique of HXR focusing optics. As a focal plane detector of FOXSI, high detection efficiency not to waste the focused photons, <100 μm position resolution to take advantage of the angular resolution of the optics, and <1 keV energy resolution (FWHM) for spectroscopy down to 4 keV are required with moderate cooling ($>$-30 degree-C).

Double-sided silicon strip detectors are used for the first FOXSI flight on 2012 to meet these criteria. To improve the efficiency of 66% and position resolution of 75 um with the silicon detectors, we developed the fine-pitch double-sided CdTe strip detector with position resolution of 65 um for the second FOXSI launch. The thickness of the detector is 0.5 mm, which has the efficiency of almost 100% for the FOXSI energy range. It have a good efficiency for higher energy photons, >50% up to 80 keV, also useful for future high energy observations. The sensitive area is 8.3 mm x 8.3 mm, corresponding to the field of view of 860" x 860" with the FOXSI focal length of 2 m. The energy resolution of <1 keV (FWHM) and low energy threshold of ∼4 keV are achieved in a calibration on the ground. The second launch of FOXSI was performed on December 11, 2014, and images from the Sun are successfully obtained with the CdTe detector. Therefore we successfully demonstrated the concept of the detector and it enabled us to plan future HXR observations of the Sun.

13.c.4 16:15 - 16:30: Lindsay Glesener: Detector requirements for solar hard X-ray measurements

- University of California - Berkeley

Co-author(s): Steven D. Christe[1], Säm Krucker[2], Shin-nosuke Ishikawa[3], Albert Y. Shih[1], Nicole Duncan[2], Juan Camilo Buitrago Casas[2], Natalie Foster[4]
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As the effective area of hard X-ray optics grows (for example, with the advent of focusing optics), their corresponding X-ray detectors must keep up with obscenely high count rates. They are expected to do this while still returning high-resolution positional and timing information and maintaining good energy resolution. Low backgrounds are also crucial in order to take full advantage of the sensitivity achievable with focusing optics. The Sun is a particularly demanding target in terms of high count rates due to large thermal fluxes.

This talk will summarize the detector requirements for future solar hard X-ray study, will give examples of detector designs that are currently used on FOXSI, RHESSI, and NuSTAR, and will discuss concepts that could meet the needs of future instruments.

13.c.5 16:30 - 16:45: Greg Kopp: Total Solar Irradiance Measurement Techniques Have Improved Radiometric Accuracy

- University of Colorado LASP

To discern changes in the Sun's radiative output over the multi-decadal and century time scales needed for Earth climate studies and to give a better understanding of solar variability, radiometric measurements of extremely high accuracy are needed. These total solar irradiance (TSI) measurements quantify the entire spatially- and spectrally-integrated radiative output from the Sun, relying on space-borne radiometers for their broad spectral coverage and high optical power measurement capabilities.

Realization over the last decade of artifacts affecting the accuracies of the classical TSI instruments first launched in the 1970's, which measured signals erroneously high by >0.3%, has retroactively improved those instruments' data. Current spaceflight instrumentation using improved designs and calibrations is nearly 30x more accurate than those first generation instruments, while imminent future versions are anticipated to bring another 3x improvement to achieve radiometric accuracies of 0.01% with on-orbit stabilities of 0.001%/year.

Electrical substitution radiometers have been the fundamental detectors for all space-borne TSI instruments, as they span the Sun's radiometric output from x-rays to the far infrared. Accurate measurement of the applied electrical heater power necessary to maintain thermal stability of a solar-pointed broadband absorptive radiometer as entering sunlight is modulated provides quantification of the incident solar radiative power. A calibrated precision aperture defines the area over which that radiant energy is collected, and the ratio of these two gives irradiance, or radiative power per area.

Modern refinements to the early, classical radiometers include improved layout of the fundamental instrument components, digital control of the applied and measured heater power, phase sensitive detection for reduced sensitivity to thermal drifts and 1/f noise, more robust absorptive materials lining radiometer cavities, on-orbit electrical servo system gain calibrations, and flight characterizations of the background ("dark") thermal contributions from the instrument itself. Improved ground calibrations include non-contact aperture area measurement techniques and end-to-end comparisons against a newly built reference standard laboratory facility based on a custom cryogenic radiometer capable of measuring irradiances at full solar power levels in a vacuum enclosure shared with the instrument under test.

I will describe the state-of-the-art TSI measurement techniques and associated spaceflight instrument designs, the realizations causing prior erroneous measurements, and the current radiometric accuracies achieved. I will also present expected improvements to those techniques with new materials and capabilities in the upcoming generation of spacecraft instruments to meet the needs given for TSI measurements in both the 2012 Heliophysics and the 2007 Earth Science decadal surveys.

13.c.6 16:45 - 17:00: Chhavi Goenka: Tunable Filter Technology in Space Plasma Research

- Boston University

Co-author(s): Joshua Semeter[1], Jeffrey Baumgardner[1], Hanna Dahlgren[2], John Noto[3]
- [1]Boston University, [2]KTH Royal Institute of Technology, [3]Scientific Solutions Inc

Space plasmas exhibit spatial, spectral and temporal variability and therefore their optical investigations benefit from measurements acquired simultaneously in these three domains. There have been numerous approaches to making such multispectral measurements, ranging from spectrographs to filter wheels and from pressure scanned systems to simultaneous multispectral imagers. Over the last decade, electro-optical tunable filters have found increased use in ground based imaging instruments for space plasma studies, owing to their ability to rapidly switch between wavelengths and provide spatial and spectral information over a large wavelength range. Additionally, the use of electro-optical filters results in compact instruments requiring minimum mechanical movement once deployed. Some examples of these instruments include a zenith spectrometer using an Acousto-Optical Tunable Filter (AOTF), an all sky hyperspectral imaging camera, the NORUSCA camera, which uses a Liquid Crystal Tunable Filter (LCTF), a four channel hyperspectral imager, LiCHI, which uses Liquid Crystal Fabry-Perot (LCFP) filters, etc. These filters and instruments offer some unique advantages but, being relatively new in the field of aeronomy, also present some equally unique challenges. This paper discusses the role of tunable filter technology in space plasma research and explores the designs and techniques used by some of these instruments.

13.c.7 17:00 - 17:15: Harald Frey: The Imager for Sprites and Upper Atmospheric Lightning (ISUAL)

- University of California - Berkeley

Co-author(s): Stephen Mende[1], Stewart Harris[1], Henry Heetderks[1], Yukihiro Takahashi[2], Han-Tzong Su[3], Rue-Ron Hsu[3], Alfred Chen[3], Yeou-Shin Chang[4], Albert Lin[4], Lou-Chuang Lee[5]
- [1]University of California - Berkeley, [2]Hokkaido University, [3]National Cheng-Kun University, [4]National Space Program Office Taiwan, [5]Academia Sinica Taiwan

The Imager for Sprites and Upper Atmospheric Lightning (ISUAL) was the first specifically dedicated instrument to observe lightning-induced transient luminous events (TLE) sprites, elves, halos, and gigantic jets from space. It consists of four major components. The Imager is an intensified CCD system operating in the visible wavelength region with a filter wheel to select from 6 positions with filters for the emissions of N2-1P (633-751 nm), O2 ATM (762 nm), OI (630 nm), OI (557.7 nm), N2-1N (427.8 nm), and an open position (400-850 nm). The Imager has a 5°x20° (vertical x horizontal) field of view (FOV). The Spectrophotometer (SP) is populated with 6 photometers with individual filters for the emissions of N2-LBH (150-290 nm), N2-2P (337 nm), N2-1N (391.4 nm), N2-1P (620-750 nm), OI (777.4 nm), and N2-2P 250-410 nm). The FOV of the photometers is designed to cover the same region as the Imager and the signal is integrated over the full FOV. An Array Photometer (AP) with two channels operating in the blue (N2-2P, 360-470 nm) and red (N2-1P, 520-750 nm) provides altitude profiles of the emission over 16 altitude bins each. The Associated Electronics Package (AEP) provides power, controls instrument functions, receives and executes commands, collects, stores and packetizes the data, and interfaces with the spacecraft. ISUAL was launched May 21, 2004 into a sun-synchronous 890 km orbit on the Formosat-2 satellite and has successfully been collecting data ever since. ISUAL is running on the night side of the orbit and is pointed to the east of the orbit down towards the limb. The instrument runs continuously and writes data to a circular buffer. The Imager integration time can be selected between 1-1000 msec, the SP is running at 10 kHz, and the AP integrates for 50 and 500 microseconds. Whenever the SP detects a sudden signal increase above a preset threshold, a trigger signal is generated that commands the system to keep the data for about 400 msec starting from ∼50 msec before the trigger. Over its lifetime of ∼11 years the system recorded thousands of TLE and also successfully observed aurora and airglow.

13.c.8 17:15 - 17:30: Steven Christe: HEXITEC Detectors

- NASA GSFC

Co-author(s): Albert Shih[1], Jessica Gaskin[2], Collen Wilson-Hodge[2], Paul Seller[3], Matt Wilson[3]
- [1]*NASA GSFC,* [2]*NASA MSFC,* [3]*Rutherford Appleton Laboratory*

High angular resolution HXR optics require detectors with a large number of fine pixels in order to adequately sample the telescope point spread function (PSF) over the entire field of view. Excessively over-sampling the PSF will increase readout noise and require more processing with no appreciable increase in image quality. An appropriate level of over-sampling is to have 3 pixels within the HPD. For current high resolution X-ray mirrors, the HPD is about 25 arcsec. Over a 6-m focal length this converts to 750 μm, the optimum pixel size is around 250 μm. Another requirement are that the detectors must also have high efficiency in the HXR region, good energy resolution, low background, low power requirements, and low sensitivity to radiation damage. For solar observations, the ability to handle high counting rates is also extremely desirable. The Rutherford Appleton Laboratory (RAL) in the UK has been developing the electronics for such a detector. Dubbed HEXITEC, for High Energy X-Ray Imaging Technology, this Application Specific Integrated Circuit (ASIC), can be bonded to 1- or 2- mm-thick Cadmium Telluride (CdTe) or Cadmium-Zinc-Telluride (CZT), to create a fine (250 μm pitch) HXR detector. The NASA Marshall Space Flight CenterMSFC and the Goddard Space Flight Center (GSFC) has been working with RAL over the past few years to develop these detectors to be used with HXR focusing telescopes. We present on recent results and capabilities as applied to solar observations.

17:30 - 19:00: Networking Mixer [NCAR Mesa Lab] – No shuttle

Thursday, April 23, 8:30 - 19:00

14 8:30 - 10:15: PLENARY – Ground (#2) [Auditorium]

Chair(s): E. Zesta

14.1 8:30 - 9:15, *Invited*: Haosheng Lin: Remote Sensing of Solar Magnetic Fields – Methods, Tools, and Future Directions

- University of Hawaii

Understanding the formation and evolution of the magnetic fields of the solar atmosphere, and how they interact and influence the dynamics of the particles of the atmosphere, are crucial for the resolution of many long-standing problems in solar and space physics. Through the interaction between the particles and magnetic fields, information about the physical conditions of the solar atmosphere are encoded in the shape and polarization properties of spectral lines originating from the solar atmosphere. However, the physical conditions of the solar atmosphere span an enormous range, from the low temperature, high density, and high magnetic field strength regime in the photosphere to the million-degree temperature, low density, and low magnetic field strength condition high up in the corona. Consequently, accurate understanding of the interactions and the spectral line formation mechanisms under different conditions, and proper design of instruments and observing techniques optimized for each condition are required to correctly infer the magnetic and thermodynamic conditions of the solar atmosphere. We will present current understanding of the spectral line polarization and formation mechanism in the photosphere, chromosphere, and the corona, and how telescopes and instruments are optimized for each region of the solar atmosphere. We will also present ideas for future instrumentation that employee massive multiplexing technology to greatly enhance the system efficiency to deliver data with the spatial, spectral, and temporal resolution and (spatial, spectral, and temporal) field of views that will allow us to finally understand the highly dynamic, and often eruptive, solar atmosphere.

14.2 9:15 - 9:45, *Invited*: Dale Gary: New Measurement Techniques in Solar Radio Physics

- New Jersey Institute of Technology

We are on the cusp of a revolution in measurement techniques in solar radio physics due to the recently or soon-to-be-completed new instruments that make use of interferometry with broader bandwidths and higher frequency- and time-resolution. The first solar observations are now available for new instruments such as the expanded (Jansky) Very Large Array (VLA), the LOw Frequency ARray (LOFAR), and Atacama Large Millimeter Array (ALMA). In addition, new or expanded solar-dedicated arrays are coming on line, such as the Expanded Owens Valley Solar Array (EOVSA), the Chinese Solar Radio-Heliograph (CSRH), and the Upgraded Siberian Solar Radio Telescope (SSRT). Other new arrays are being developed with solar science in mind, such as the Long Wavelength Arrays (LWA) at the VLA and Owens Valley sites, and the Murchison Widefield Array (MWA) in Australia. This talk will use some of the exciting new results already obtained from early observations with these new instruments, as well as modeling, to illustrate the science to come in the near future.

14.3 9:45 - 10:15, *Invited*: Joshua Semeter: Imaging science at visible wavelengths

- Boston University

In its most general description, an optical imaging system measures photon flux as a function of azimuth, elevation, wavelength, polarization, and time. System design always involves trading reduced fidelity in one dimension for increased fidelity in another (subject to restrictions on size, weight, power, and complexity); and the core objective of technology development is to decrease the degree to which such tradeoffs are required. One example is the emergence of CMOS detectors. The disruptive increase in frame rate, originally limited to full-light conditions,Êhas since been extended to low-light signals, allowing the same spatial and temporal fidelity to be available in space applications. A second exampleÊis electronically tunable filters, original used in interferometric systems (addressing time and wavelength fidelity) but recently adapted to wide-field imaging applications (addressing spatial fidelity). Indirect but equally compelling examples derive from general advances in memory and computing power, which have enabled high frame-rate sampling for long intervals and rapid production of high-level data products, such as tomographic reconstructions and data assimilations. This talk reviews current trends in imaging science within the context of this trade-space framework and presents a vision for the near future.

15 10:30 - 12:15: PLENARY – Particles (#2) [Auditorium]

Chair(s): D. Gershman

15.1 10:30 - 11:05, *Invited*: Eberhard Moebius: Time-of-Flight Mass Spectrometers – From Ions to Neutral Atoms

- University of New Hampshire

After their introduction to space physics in the mid 1980's time-of-flight (TOF) spectrometers have become a main staple in space bound mass spectrometry. They have largely replaced magnetic spectrometers, except when extremely high mass resolution is required to identify diverse complex molecules, for example in the vicinity of comets or in planetary atmospheres. In combination with electrostatic analyzers and often solid state detectors, TOF spectrometers have become key instruments for the diagnostics of space plasma distributions as well as their mass and ionic charge composition. With a variety of different implementation schemes that also include isochronous field configurations, TOF spectrometers can respond to diverse science requirements. This includes a wide range in mass resolution to allow the separation of medium heavy isotopes or to simply provide distributions of the major species, such as H, He, and O, if the information on source tracers or the mass fluxes are needed. With a top hat analyzer at the front end, or in combination with deflectors in the case of 3-axis stabilized spacecraft, the distribution function of ions can be obtained with good time resolution. Most recently, the reach of TOF ion mass spectrometers has been extended to also include energetic neutral atoms. After selecting the viewing direction with mechanical collimation, followed by conversion to ions, TOF spectrometers from previous ion sensors form a new branch of the spectrometer family tree. The requirements, challenges, and implementation schemes for ion and neutral atom spectrometers will be reviewed, including ideas and directions for the future.

15.2 11:05 - 11:40, *Invited*: David Knudsen: Fast Core Plasma Diagnostics

- University of Calgary

The need for fast plasma diagnostics is driven by the fact that active plasma regions are often structured on scales of hundreds of meters or even less, requiring temporal resolutions of tens or hundreds of ms. Core particle measurements are subject to additional challenges that do not apply to their higher-energy counterparts, as low-energy particle trajectories are affected by wakes, spacecraft charging, and stray fields and gyro motion within instruments. Furthermore, core ion distributions are strongly distorted by spacecraft motion, making reconstruction difficult. This talk will review these and other other aspects of core plasma diagnostics, along with techniques used to address them.

15.3 11:40 - 12:15, *Invited*: Miguel Larsen: Diagnosing Winds Aloft

- Clemson University

Chemical tracer releases, in the form of either clouds or trails, have been used extensively throughout the history of sounding rocket launches to measure winds and plasma drift motions in the mesosphere and thermosphere. Measurement programs using these techniques were especially active in the 1960's and 1970's, although application of the techniques have continued until the present day. During the last decade, technical advances have made it possible to extend the measurement capabilities substantially. Recent results include thermospheric wind profile measurements in daytime conditions and F-region wind profiles at night at arbitrary times using lithium trails. In the past, lithium trail measurements have generally been limited to brief windows in twilight conditions. In addition, three-dimensional arrays of small-cloud releases from a single rocket have been demonstrated to provide both horizontal and vertical flow gradient measurements. Finally, new techniques for extracting turbulence characteristics from trimethyl aluminum tracer trails have been developed and applied in several observations of the mesosphere and lower thermosphere. The use of various types of tracers for diagnosing the neutral winds in the upper mesosphere and thermosphere will be reviewed, as well as the recent technique developments and applications.

16 13:15 - 15:00: PARALLEL SESSIONS – Photons, Particles, Ground

16.a Photons – Algorithms & Techniques [North]

Chair(s): M. Kirk

16.a.1 13:15 - 13:30: Solomon Stanley: An Observation Simulation System for the GOLD and ICON Missions

- *NCAR*

Co-author(s): Scott England
- *University of California - Berkeley*

We are developing a comprehensive observing simulation system for remote sensing observations by the GOLD and ICON missions. These NASA missions to perform comprehensive measurements of the terrestrial thermosphere and ionosphere are planned for launch in 2017. Instrument development, algorithm development, and ultimately data analysis, depend on a robust capability for simulating what we expect the instruments to observe. Therefore, we are building a flexible software system that will serve both missions. The system will use calculations from general circulation models of the atmosphere-ionosphere system as input to an airglow model, perform spectral synthesis calculations, and apply observational parameters to predict what the instruments may observe from generalized viewing geometry. We will describe the system architecture and methodology, and present preliminary simulation results.

16.a.2 13:30 - 13:45: Michael Kirk: Software Techniques for Removing Noise from Solar Images

- *NASA GSFC*

Co-author(s): C. Alex Young
- *NASA GSFC*

Noise is present in any measurement due to both instrumental and random effects. In most solar imaging, we have the luxury of high photon counts and low background contamination. A high signal to noise ratio, which when combined with carful calibration, minimize much of the impact noise has on any measurement. Outside high signal-to-noise measurements, such as images of high-temperature plasma, the noise component can become significant and impede feature recognition and segmentation. A Poisson-Gaussian model of noise is well suited in the digital imaging environment due to the statistical distributions of photons and the characteristics of the CCD. We create a practical estimate of noise in the AIA images across the detector CCD using a variety of statistical techniques. We then contrast the effectiveness of these algorithms at removing noise from level-1 AIA images. This systematic estimation and removal of noise provides a clearer view of solar features in AIA. We further discuss the relevance of these routines to characterize noise in other solar images.

16.a.3 13:45 - 14:00: Andrew Stephan: Advances in remote sensing of the daytime ionosphere with EUV airglow

- *Naval Research Laboratory*

Co-author(s): Kenneth Dymond, Scott Budzien, Andrew Nicholas
- *Naval Research Laboratory*

We describe a method for characterizing the daytime ionosphere from limb profile measurements of the OII 83.4 nm emission. This extreme-ultraviolet (EUV) emission is created by solar photoionization of atomic oxygen in the lower thermosphere, and is resonantly scattered by O+ in the ionosphere. The brightness and shape of the measured altitude profile thus depend on both the photoionization source in the lower thermosphere and the ionospheric densities that determine the resonant scattering contribution. This technique has greatly matured over the past decade due to measurements by the series of Naval Research Laboratory Special Sensor Ultraviolet Limb Imager (SSULI) instruments flown on Defense Meteorological Satellite Program (DMSP) missions and the Remote Atmospheric and Ionospheric Detection System (RAIDS) on the International Space Station. The volume of data from these missions has allowed the advancement of approaches to handle possible biases in the measurements. Additionally, simultaneous measurements of the OII 61.7 nm emission have been shown to reflect changes in the brightness of the source in the lower thermosphere, providing a means to directly address this factor in the ionospheric retrieval.

We will review the current state of this technique for measuring the daytime ionosphere, its application for the upcoming Ionospheric Connection Explorer (ICON) and the Limb-Imaging Ionosphere and Thermosphere EUV Spectrograph (LITES) missions, and the benefits of merging these ionosphere measurements with complementary far-ultraviolet airglow measurements to provide a comprehensive view of the daytime ionosphere-thermosphere system.

16.a.4 14:00 - 14:15: Scott Budzien: Advanced EUV/FUV Techniques for Remotely Sensing the Thermosphere and Ionosphere using SSULI

- *Naval Research Laboratory*

Co-author(s): K Dymond[1], A Nicholas[1], M Hei[2], A Stephan[1], C Coker[1]
- [1]*Naval Research Laboratory,* [2]*Sotera Defense Inc.*

Global-scale information about the space environment and its dependence upon solar and geomagnetic influences is more important than ever to our space-dependent society. The ionosphere is the most variable component of the atmosphere: electron and plasma density can vary by orders of magnitude with respect to local time, latitude, season, solar cycle, and geomagnetic conditions, and ionospheric variability affects numerous civilian systems and military systems. As we transition from space weather specification to a forecasting paradigm, however, mere specification of the current ionosphere and global TEC is insufficient. Accurate ionospheric forecasting also has strong dependence on the thermospheric density and composition.

The Special Sensor Ultraviolet Limb Imager (SSULI) instruments aboard the Defense Meteorology Satellite Program (DMSP) satellites remotely sense the upper atmosphere in the extreme- and far-ultraviolet passband. SSULI measures daytime and nighttime ionospheric density profiles and daytime themospheric density and composition from low Earth orbit. New remote sensing algorithms, tomographic retrieval techniques, and multi-sensor approaches improve the coverage and accuracy of SSULI space environment measurements. SSULI and follow-on instruments will provide key measurements for next-generation global ionosphere assimilation models.

16.a.5 14:15 - 14:30: Richard Schwartz: Image Recovery Using the Diffraction Kernel

- *NASA GSFC*

Co-author(s): Gabriele Torre, Michele Piana, Hazel Bain, Claire Raftery, Säm Krucker, Annamaria Massone
- *University of Genoa, University of California - Berkeley*

Solar flares are easily seen in movies made with data from AIA on SDO or from TRACE. Typically what is noticed is a uniform bright patch with a series of rays emanating from the core. In reality, the actual flaring region is quite small and with considerable structure but this totally obscured by the CCD saturation level plateau. In movies that include exposure control frames there is a blinking effect between fully and partially saturated data. Shortened exposures are no solution to this problem as they often still have saturation for fast-rising or intense flares and have a reduced cadence. To studies flare kernels, bright filaments, and hot loops at the instruments highest cadences we have developed analysis techniques that use the pronounced diffraction fringes at these times. The mathematical methods we use were developed by noting the similarity between the diffraction rays and the time modulated count rates we use to make RHESSI images. In both cases we have an instrument model that predicts the signal given an image. Essentially we have adapted a Lucy-Richardson technique we use in RHESSI to build flare images at EUV wavelengths. Moreover, this technique is readily adaptable to the same problem in TRACE as well as several bands from STEREO EUVI. The software we develop is part of the new DESAT package within SSW. As the diffraction order distance is a linear function of the wavelength we are using dispersion to reveal the true spectral distribution in the passbands. As a final note this effect could be employed as a primary feature of some future instrument. Using this the instrument would have a tremendous upper limit to its dynamic range as it would be virtually impossible to saturate. And by casting the diffraction onto some portion of a CCD out of direct view the problem of background correction would be eliminated.

16.a.6 14:30 - 14:45: Craig DeForest: 3-D Tracking of CMEs and other solar wind features using polarized heliospheric imaging

- *Southwest Research Institute*

Co-author(s): Tim Howard, James Tappin
- *Southwest Research Institute, Rutherford Appleton Laboratory*

Heliospheric imaging is simple in concept but difficult in practice because of the need to separate the faint Thomson scattered signal from the far brighter background starfield. With the successful demonstration by STEREO of feature excess photometry in the solar wind, it is now feasible to exploit the polarization effects of Thomson scattering. In particular, it would be possible to locate features - including CMEs - in 3-D to within a few degrees, using an instrument with similar characteristics to STEREO/HI and a variable linear polarizer. The technique has advantages over stereoscopy and over similar techniques used in the corona. We will present inversion methods, noise analysis, and a demonstration of the technique using forward modeling of an actual Earth directed CME.

16.a.7 14:45 - 15:00: Veronique Bommier: Milne-Eddington Inversion of Unresolved Structures

- LESIA Observatoire de Paris

We have developed an inversion procedure, of the Milne-Eddington type, able to take into account unresolved magnetic structures like fluxtubes. Our approach is original, and has been successfully tested and validated (Bommier et al., 2007, A&A 464, 323). Since the pioneer work by Stenflo (1974), it is known that the solar network magnetic field is made of kG fields, but filling only 1-2% of space. With the present instruments, these structures are yet unresolved, so that a magnetic filling factor has to be introduced in the inversion. We will present our method for modeling the magnetic filling factor, and the expected results in terms of magnetic vector coordinates. In the center of sunspots the magnetic filling factor is unity and its taking into account unnecessary, but farther from the center, weaker is the filling factor, and we will show that our model provides better field inclinations and azimuths in these regions. We show that our inversion retrieves the "local average magnetic field", which is the product of the magnetic field strength by the magnetic filling factor, but not each of them. In the case of quiet sun observations, we were able to independently determine an order of magnitude of the magnetic filling factor, so that the magnetic field strength was also finally determined, in agreement with Stenflo's pioneer work.

16.b Particles – Thermal/Core Plasmas [Center]

Chair(s): G. Clark

16.b.1 13:15 - 13:35, *Invited*: Rod Heelis: Satellite Measurements of Thermal Ion Drifts and Temperature

- University of Texas - Dallas

In this presentation we describe various issues associated with *in-situ* measurement of the temperature and drift of very low energy ions. A sensor on an orbiting vehicle will generally measure the ion flux at a specified energy and a specified acceptance solid angle. In many cases the orbital velocity of the sensor is much larger than the thermal velocity of the ions and in such cases appropriate consideration of ion trajectories inside the sensor allow the shape of the distribution function and the centroid of the distribution function to be located in three mutually perpendicular directions. This information can be used to specify the bulk ion drift and a Maxwellian temperature. Here we will describe the function of different sections of a typical sensor that selects the ion species energy prior to detection and discuss the various impacts of spacecraft and grid potentials on the derivation of geophysical parameters.

16.b.2 13:35 - 13:55, *Invited*: Aroh Barjatya: Langmuir probes in the ionosphere and mesosphere lower thermosphere

- Embry-Riddle Aeronautical University

Co-author(s): David Cooke[1], Patrick Roddy[1], Tore-Andre Bekkeng[2], Charles Swenson[3]
- [1] Air Force Research Laboratory, [2] University of Oslo, [3] Utah State University

Langmuir probes are ubiquitously used for *in-situ* plasma density and temperature measurements from mesosphere-lower-thermosphere through to upper ionosphere. This paper first reviews the basic technique and briefly discusses its various implementations and challenges for sounding rockets and satellites. As has been widely reported before, the background theory is not a limitation but rather it is the engineering implementation that can lead to errors in the derived plasma parameters. In our discussion particular emphasis would be placed upon implementations of the technique in the past two decades: planar Langmuir probes, multi-needle probes and a unique implementation of a fast temperature probe. We will present data from several of these instruments from their recent rocket/satellite flights.

16.b.3 13:55 - 14:08: Nikolaos Paschalidis: Advanced gated time of flight mass spectrometers for Small Satellites and Cubesats

- NASA GSFC

Co-author(s): Sarah Jones[1], Ed Sittler[1], Marcello Rodriguez[1], Dennis Chornay[1,2]
- [1]NASA GSFC, [2]University of Maryland

The time of flight technique is widely used for composition analysis of space plasma instruments. The foil – MCP/CEM combination is commonly used for E x TOF mass analysis at the cost of energy threshold, scattering, and direct particle interaction which ultimately affect performance. An alternative method especially effective at low energies is gated time of flight where the start foil is replaced with electric gating. There are several advantages of electric gating, including elimination of heavy HVPS required for pre-reacceleration to overcome foil thresholds, non- destructive interaction with atomic and molecular ions before analysis, and electronic controllability including geometric factor adjustment for flux dynamic range, FOV optimization, and other properties affecting directly the scientific and engineering performance of the instruments. Those characteristics will be elaborated in the context of a gated time of flight Ion and Neutral Mass Spectrometer (INMS) developed at GSFC. The INMS is the main payload of the EXOCUBE cubesat mission and is baselined for the GSFC Dellingr mission and other missions

16.b.4 14:08 - 14:21: Andrew Nicholas: Winds-Ions-Neutral Composition Suite Design and Performance

- Naval Research Laboratory

Co-author(s): Federico Herrero, Theodore Finne
- Space Systems Research Corporation, Naval Research Laboratory

The Winds-Ions-Neutral Composition Suite (WINCS) instrument, also know as the Small Wind and Temperature Spectrometer (SWATS), was designed and developed jointly by the Naval Research Laboratory (NRL) and NASA/Goddard Space Flight Center (GSFC) for ionosphere-thermosphere investigations in orbit between 120 and 550 km altitude. The WINCS design provides the following measurements in a single package with a low Size, Weight, and Power (SWaP): 7.6 x 7.6 x 7.1 cm outer dimensions, 0.75 kg total mass, and about 1.3 Watt total power: neutral winds, neutral temperature, neutral density, neutral composition, ion drifts, ion temperature, ion density and ion composition. The *in-situ* instrument suite WINCS is described showing how the Small Deflection Energy Analyzer (SDEA) concept is used to measure the neutral wind and the ion-drift and how the SDEA served to define the mass spectrometer also used in WINCS to measure ion and neutral composition. In addition to the trajectory calculations, the operational characteristics of the instrument suite are also described. The paper will discuss the calibration techniques and on-orbit results of the instrument.

16.b.5 14:21 - 14:34: Russell Stoneback: Updating the Ion Velocity Meter for CubeSats

- University of Texas - Dallas

Co-author(s): Rod Heelis
- University of Texas - Dallas

Ion Velocity Meters (IVM) have been used on numerous satellite missions to measure thermal plasma properties and have traditionally been comprised of at least two instruments, a Retarding Potential Analyzer (RPA) and a Drift Meter (DM). The RPA measures the direct current collection of ions as a function of retarding voltage. Fitting the measured currents to a theoretical curve yields ion density, composition, temperature, and ion velocity along the satellite track. The DM measures the arrival angle of ions which may be used with satellite orbit and attitude information to obtain the cross-track ion velocities.

The upcoming Scintillation Observations and Response of the Ionosphere to Electrodynamics (SORTIE) CubeSat mission is scheduled to have both an IVM as well as a planar Langmuir probe to investigate the presence of waves in the ionosphere and the formation conditions for plasma bubbles. CubeSats are a significantly smaller spacecraft than those previously used by IVM instruments thus we detail updates to the IVM to combine both measurement functions into a single, smaller, and more capable package. Given the mission focus on ionospheric waves and irregularities new IVM modes are also in development to increase the range of irregularity scale sizes resolvable by the instrument.

16.b.6 14:34 - 14:47: Ian Cohen: Rocket-borne Measurements of Electron Temperature with the Electron Retarding Potential Analyzer (ERPA) instrument

- University of New Hampshire

Co-author(s): Marc Lessard, Mark Widholm, Paul Riley
- University of New Hampshire

The determination of electron temperature in the ionosphere is a fundamentally important measurement for space science. Obtaining measurements of electron temperatures at high altitudes (>700 km) is difficult because of limitations on ground-based radar and classic spacecraft instrumentation. In light of these limitations, the rocket-borne Electron Retarding Potential Analyzer (ERPA) was developed to allow for accurate *in situ* measurement of ionospheric electron temperature. By combining elements of a Faraday Cup and a retarding potential analyzer, the compact ERPA minimizes gryoradius effects and allows for a simple, straightforward calculation of electron temperature. Since its first flight on the SERSIO mission in 2004, it has amassed significant flight heritage and obtained data used in multiple studies investigating a myriad of phenomena related to magnetosphere-ionosphere coupling.

16.b.7 14:47 - 15:00: Jeff Klenzing: The effect of light ions on the collection efficiency of "fixed-bias Langmuir Probes and Ion Traps"

- NASA GSFC

Co-author(s): R. Pfaff, D. Rowland, R. Albarran, P. Roddy, R. Stoneback
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Since the dawn of the space age, thermal plasmas have been measured by direct current collection of ions by biased collectors on both satellites and suborbital platforms. The accurate measurement of number density from the current collected by such probes requires knowledge of the ambient ion species as well as the ion temperature. In particular, the presence of light ions, such as hydrogen and helium, can severely affect the determination of plasma number density from such fixed-bias Langmuir probes and ion traps. Accurate measurements of density fluctuations also requires that ratio of the vehicle velocity to the thermal velocity of the plasma be constant; however, many plasma density structures in the ionosphere consist of changes in composition in addition to density fluctuations. For a spherical probe, the difference in current collected for an O+ and H+ plasma is roughly a factor of six. This leads to to a potential masking effect of density enhancements, decreasing the utility of these probes in inferring the relative density fluctuations.

Using a seven-year database of measurements from multiple probe geometries on board the C/NOFS (Communication/Navigation Outage Forecasting System) Satellite, we discuss the effect of light ions on the current collection of spherical and planar Langmuir probes, as well as Ion Trap designs where the collection surface is held behind a series of biased grids. Through comparative analysis with simulations, we discuss potential strategies with respect to future satellites and sounding rockets.

16.c Ground – Radio 2 and Optical 2 [South]

Chair(s): S. Kaeppler

16.c.1 13:15 - 13:35, *Invited*: Diego Janches: Progress in Neutral Dynamics and Meteor Studies Utilizing Advance Design Meteor Radars

- NASA GSFC

Co-author(s): David C. Fritts, Wayne K. Hocking
- Gats Inc., University of Western Ontario

Specular radio-wave scatter from meteor trails for atmospheric studies has been utilized since the end of WWII. The method was prominent until the early 1970s for measurement of mesopause winds and meteor studies when it was replaced by other techniques such as the Medium Frequency (MF) spaced antenna radars, which could cover wider altitude range and was sensitive to gravity waves (GWs) on shorter temporal scales. In the early 1990s when faster computers become more accessible and multiple receiver systems, using a special 5-receiver spaced antenna pattern enabled the application of interferometry, meteor radars experienced a rebirth. Individual meteors and their precise location could be better identified, and improvements in design, mainly using pulsed radars and higher frequency rates led to increase in meteor count rates to thousands per day. The addition of these techniques resulted in an ideal instrument for the study of neutral winds, tides and Planetary Waves (PWs) in the Mesosphere and Lower Thermosphere (MLT) and also the development of the potential to measure temperatures. The expected big Leonids meteor storm in the late 1990s also renewed the interests of the dust astronomy community. In some cases, the addition of remote receiving sites enable these systems to determine meteoroid orbital parameters. This technique measures the time delay between the detection of the specular meteor trail at different sites formed by the same event. More recently enhancements relative to standard meteor radars were introduced in order to enable GW momentum flux measurements in the MLT. These enhancements include greater transmitter peak power and the use of transmitter phase antenna array configurations, which are significantly different from typical systems that use a single antenna. In addition, the ability to change electronically (e.g., pulse to pulse) the phases between antennas provides great flexibility to the systems, since it allows transmission with different radiation patterns and hence permits performance of a number of different experiments, such as the routine detection of meteor head echoes and non-specular trails, only possible before using incoherent scatter radars. In this talk we will review this progress and discuss the measuring capabilities of these enhanced systems.

16.c.2 13:35 - 13:48: Xinzhao Chu: Ground-based Optical and Radio Remote Sensing Cluster at Boulder (40°N, 105°W), Colorado for Geospace Observation

- University of Colorado - Boulder

Co-author(s): Xinzhao Chu[1], Wentao Huang[1], Xian Lu[1], John A. Smith[1], Scott Palo[1], Qian Wu[2], Terry Bullett[1], Cody Vaudrin[1]
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The Space-Atmosphere Interaction Region (SAIR) is an intersection between geospace and the EarthÕs atmosphere encompassing the mesosphere, thermosphere and ionosphere. It is exposed to and clearly affected by vacillating conditions of both space and terrestrial weather. The atmospheric neutral gases and the dynamic plasma of space mingle and interact strongly in this region. The understanding of SAIR and its predictability are fundamental in Solar and Space Physics, which require sophisticated observations of both neutrals and plasma. However, measurements of the neutral thermosphere are rare, and the lack of coordinated neutral and plasma observations is hindering the advancement in this field. At Boulder, Colorado, there has been developing of a cluster of ground-based optical and radio remote sensing instruments capable of exploring the SAIR, including lidars, meteor wind radar (MWR), Fabry–Pérot interferometers (FPIs), and ionosonde. These active and passive instruments can simultaneously observe multiple aspects of the SAIR at the same location and provide comprehensive information.

Through optimizing a Na Doppler lidar and developing the next-generation Fe Doppler lidar, the lidar group at CU now established two powerful resonance fluorescence lidars at Table Mountain, Boulder. Although the Doppler lidars utilize the neutral metal layers as tracers, their measurement can reach high in the thermosphere attribute to their superb signal levels and the occurrences of thermosphere metal layers, which are discovered recently at several locations globally (e.g. Fe layers up to 170 km and Na layers up to 140 km in Antarctica, and thermosphere Na layers in mid-latitude). This provides unique opportunities to study the plasma-neutral coupling and the impacts of gravity waves and tides in SAIR. In the mesopause region, both lidars can measure corresponding neutral metal density, temperature, and winds with high resolutions, up to several seconds in time and tens of meters in altitudes. Such high-resolution measurements enable the investigation of the vertical heat and constituent transport by gravity waves and turbulent eddy mixing in SAIR. CU MWR group are developing the new CoSRad (Colorado Software Defined Radar) equipped with multiple interferometric receiver stations, which will greatly increase both temporal and vertical resolution of range-resolved wind measurements. Along with the high-resolution lidar observations and airglow measurements, it can fully resolve the characteristics of gravity waves with periods from minutes to hours. These gravity waves can often be traced downward to their source regions using lower-atmosphere reanalysis dataset while their impacts on the ionospheric and thermospheric variability can be observed by ionosonde and FPI measurements. From this analysis with vertical extension from nearly surface to the upper atmosphere, the impacts of terrestrial weather on geospace variability can be assessed.

The exceptional observational capability of combining these ground-based instruments will help answer the following compelling science questions: 1) how plasma-neutral coupling processes and atmospheric waves shape the ionospheric structure and variability; 2) what are the magnitudes of the vertical heat, constituent and momentum transport by tides, gravity waves and turbulence; and 3) how terrestrial weather impacts the geospace variability via vertical wave coupling.

16.c.3 13:48 - 14:01: Nikolay Zabotin: Dynasonde methods as the future of ionospheric radio sounding

- University of Colorado - Boulder

Co-author(s): Michael Rietveld, Terence Bullett

- EISCAT Scientific Association, NOAA National Geophysical Data Center

'Dynasonde' is a generic name for an ideology of precision ionospheric radio sounding which commenced development in the mid '60s at NOAA's forerunner in Boulder, Colorado, the Institute for Telecommunication Sciences and Aeronomy. The name itself was chosen in 1969 to denote "a system competent to sound the full range of dynamic variation of the ionosphere". In Dynasonde data analysis, the Radio Echo is considered the basic physical object. High resolution raw I & Q data provided by modern digital radar hardware with high performance analog front ends is carried over to precisely determined echo physical parameters such that ionospheric roughness determines their actual uncertainties. Special attention is paid to complete use of phase information in the echo. No Fourier transforms; no pulse coding; no coherent summations are applied nor needed. The phase and amplitude of received signals (from raw I & Q) are used directly. In consequence, Dynasonde analysis yields excellent statistics of recognized echoes (up to several thousand per ionogram recording). The same echo recognition and characterization process rejects false echoes and noise very efficiently. An echo is defined by 7 parameters (two angles of arrival, group range, Doppler, polarization, phase range, amplitude), each with its individual uncertainty estimate. Processing the list of the echo parameters instead of traditional amplitude-based image analysis is the distinctive property of a Dynasonde system. This technique turns radar into a measuring system, not merely imaging system.

High precision of physical parameters and rich statistics of recognized echoes provide conditions for excellent quality and dependability of higher-level processing results. Products of autonomously operating Dynasonde data analysis include standard parameters of the ionospheric E, F regions; vector velocities characterizing movement of plasma contours; quantitative parameters of the km-scale irregularity spectrum. 3-D plasma density inversion, 'NeXtYZ', provides, for the first time in ionospheric radio sounding practice, the true vertical profile of plasma density and the vertical profile of horizontal gradients. NeXtYZ implements the only available algorithm for profile uncertainty calculations that satisfies the requirements of Kalman-filter-based assimilative ionospheric models. As has been recently demonstrated, the Dynasonde profiles of the electron density and of the horizontal gradients, complemented with profiles of the Doppler speed, carry comprehensive quantitative information about Atmospheric Gravity Waves, a ubiquitous feature of the space weather that has become an important objective of atmospheric modeling. Being combined into a time series, the profiles, without additional processing, allow visualization of the time fronts of the Traveling Ionospheric Disturbances (TIDs). They also provide high-resolution input data for calculating the complete set of parameters (both vertical and horizontal) of TID activity in the upper atmosphere between the base of the E layer and the maximum of the F layer. Application of the Lomb-Scargle periodogram technique to the tilt data provides unique insight into the dynamics of spectral composition of the TIDs. A similar technique applied to longer time series allows determining characteristics of thermospheric tides. Note that all the mentioned products of the Dynasonde data analysis require a single, standard ionogram mode of radar operation.

16.c.4 14:01 - 14:14: Brian Jackel: Calibration of auroral optical instruments using astronomical sources.

- University of Calgary

Ground-based observations of optical aurora provide important information about conditions in the local ionosphere and along magnetic field lines which connect to distant geospace regions. Combinations of different instruments at multiple locations enable multi-scale studies spanning hundreds of meters to thousands of kilometers. Quantitative intercomparison and analysis of data requires that observations be mapped to common coordinate systems and expressed in terms of absolute intensities. This can be challenging for a wide variety of instruments and operating modes producing many different data streams.

These issues are critical to the success of large networks of optical instruments (e.g., MIRACLE, THEMIS-ASI, AGO, GO-Canada). Existing methods for geospatial referencing of auroral emissions can be sufficiently precise for many applications, depending on uncertainties in emission height. However, emission intensities are still frequently communicated in terms of arbitrary data numbers which cannot be directly connected to physical quantities of interest such as precipitation energy.

Photometric calibration is often the critical factor which limits quantitative analysis. This is partly due to the difficulty of using standard photometric references for both laboratory and field calibration. Variability in atmospheric transmission and scattering can also have a profound impact on auroral observations, particularly at lower elevation angles.

In this paper we demonstrate the use of astronomical sources for long-term absolute calibration of auroral instruments, using only data collected in the field during regular operation. This approach can be extended to include other existing instruments and applied retrospectively to certain historical data sets. While the underlying principles are not new to auroral physics, recent availability of absolutely calibrated astronomical observations should allow increasingly sensitive auroral instruments to provide continuously cross-calibrated data. This would benefit existing analysis methods, and is essential for optimal utilization of the optical aurora for geospace remote sensing.

16.c.5 14:14 - 14:27: Jayachandran Thayyil: Expanded Canadian-High Arctic Ionospheric Network (ECHAIN)

- University of New Brunswick

Polar cap ionospheric measurements are important in the complete understanding of the various processes in the Solar Wind - Magnetosphere - Ionosphere (SW-M-I) system as well as space weather applications. Currently polar cap region is lacking high-temporal and spatial resolution ionospheric measurements because of the satellite orbital limitations and sparse ground based measurements. Canada has a unique advantage because of the most accessible landmass in the high-arctic regions and Expanded Canadian High-Arctic Ionospheric Network (CHAIN) is designed to take advantage of the Canadian geographic vantage point for the better understanding of the Sun-Earth system.

ECHAIN is a distributed array of ground based radio instruments in the Canadian High-Arctic. Instruments components of ECHAIN are 25 high-data rate (100 Hz sampling) GPS receivers and six Canadian Advanced Digital Ionosondes (CADIs). This presentations will describe a brief overview of the scientific capabilities, instrument details of the ECHAIN, The presentation will also provide new scientific results and technical developments using ECHAIN measurements.

16.c.6 14:27 - 14:40: Irfan Azeem: Geospace and Space Weather Monitoring from Unmanned Marine Vehicles

- ASTRA LLC.

Co-author(s): Geoff Crowley, Adam Reynolds
- ASTRA LLC.

Oceans cover about 70% of the Earth's surface. Our capability for monitoring the geospace environment from the vast stretches of the open ocean remains a technological challenge. Traditional ground-based ionospheric and upper atmospheric monitoring systems (e.g. ionosondes, imagers, interferometers) have been bulky, power intensive and have not been demonstrated to successfully operate from a platform in the open ocean. ASTRA is developing capabilities for hosting small size, weight, and power (SWaP) geospace instruments on unmanned marine vehicles. As part of this effort, ASTRA has developed innovative technologies for its dual-frequency GPS receiver enabling accurate TEC and scintillation measurements from various moving platforms, including unmanned marine vehicles.

In this talk, we will review the challenges of ionospheric remote sensing from the ocean surface. This lack of ocean-based monitoring has rendered a large percent of the Earth's surface inaccessible for routine scientific measurements of the geospace environment. We will describe our efforts for integrating a dual-frequency GPS-receiver on a robotic marine vehicle for ionospheric TEC and scintillation monitoring. Results from recent field tests off the coast of Hawaii and Peru will be presented to demonstrate the feasibility of operating GPS receivers on ocean buoys to make persistent TEC and scintillation measurements. Future plans for extending the capabilities of the unmanned marine vehicle to support other instruments, such as imagers and interferometers, will be discussed.

16.c.7 14:40 - 14:53: Hanna Dahlgren: Investigating the electrodynamics and energy characteristics of auroral structures at high resolution by optical methods

- KTH Royal Institute of Technology & University of Southampton

Co-author(s): Betty Lanchester[1], Nickolay Ivchenko[2], Sam Tuttle[1], Daniel Whiter[1]
- [1] University of Southampton, [2] KTH Royal Institute of Technology

Technological advances leading to improved sensitivity of optical detectors have revealed that auroral displays contain a richness of dynamic and thin filamentary structures, but the source of the structured emissions are not fully understood. In addition, high resolution radar data have indicated that thin auroral arcs can be correlated with highly varying and large electric fields, but the detailed picture of the electrodynamics of auroral filaments is yet incomplete. The ASK (Auroral Structure and Kinetics) instrument is a state-of-the-art ground-based instrument designed to investigate these smallest auroral features, by using three EMCCDs in parallel for three different narrow spectral regions, and with optics giving a field of view of only 3.1° x 3.1°. The three cameras are co-aligned and are capturing simultaneous images with a frame rate of up to 32 Hz. Two of the ASK channels are providing information on the characteristic energy of the precipitating electrons, by monitoring molecular emissions (either O2+ at 562.0 nm or N2 at 673.0 nm) sensitive to high energy precipitation and an atomic oxygen emission (O at 777.4 nm) caused by foremost low energy precipitation, respectively. The relative brightness of these two emissions are compared with the brightness modelled by a combined electron transport and ion chemistry model, to derive the characteristic energy and energy flux of the precipitation causing the auroral forms. The method has been used to investigate the energy and energy flux variations within precipitating electron populations producing auroral fine scale structures. The third ASK imager measures emissions from a forbidden O+ ion line at 732.0 nm, which has a radiative lifetime of 5 s, providing a possibility to directly observe plasma drifts in the topside ionosphere. By carefully modeling the O+ emissions and comparing with observations, the plasma motion in the region within the ASK field of view can be determined at high temporal resolution. The electric fields are then calculated using the E x B drift. The method is thus a powerful tool to investigate the detailed electrodynamics and current systems around the thin auroral filaments.

16.c.8 15:53 - 15:06: Michael Hirsch: High frame-rate tomographic analysis of the aurora

- Boston University

Co-author(s): Joshua Semeter, Matthew Zettergren, Hanna Dahlgren
- Boston University, Embry-Riddle Aeronautical University, KTH Royal Institute of Technology

With increasing capabilities in deeply cooled electron multiplying CCD (EMCCD) cameras as well as increasing microprocessor power and storage capacity, long term (all night, for years) 100+ frames/sec. optical observations of aurora have been shown feasible. More than just a collection of astonishingly dynamic auroral video, by tightly time synchronized observations of two or more such cameras, tomographic reconstruction using a first principles physical model yields new insight into the fine dynamics of primary electron precipitation into the ionosphere down to the millisecond scale. Ground based observations provide the only realizable means of persistent measurements of these decameter scale width morphologies evolving on millisecond timescales for series of explosive auroral events lasting many minutes. We have developed machine vision algorithms using open source software (Python, OpenCV) to process a full night of auroral video in a few hours, detecting the presence or absence of aurora with high reliability and retaining only the video segments containing aurora.

The High Speed Tomography (HiST) instrument contributes to the global synoptic perspective by providing multi-year persistent observations with little user intervention needed. Satellites in working condition such as FAST have been abandoned on-orbit due to lack of funds to simply run the downlink data stream. Transformative helioscience system observations over an entire solar cycle(s) require systems that take a different approach to systems engineering than legacy systems that assumed frequent human interaction or maintenance. The philosophies and realized algorithms and systems we describe are necessary in the face of tightened budgets and limited human capital. The techniques we use to study the fine scale spatio-temporal dynamics of the magnetospheric drivers of the aurora can be adapted to other instruments and meta-instruments studying magnetosphere-ionosphere-thermosphere coupling.

17 15:30 - 17:00: PARALLEL SESSIONS – Photons, Particles, Fields

17.a Photons – Misc [North]

Chair(s): A. Caspi

17.a.1 15:15 - 15:30: Harald Frey: Calibration and testing of wide-field UV instruments

- University of California - Berkeley

Co-author(s): Stephen Mende, Jerome Loicq, Serge Habraken
- University of California - Berkeley, Centre Spatial de Liege, University of Liege

As with all optical systems the calibration of wide-field ultraviolet systems includes three main areas: sensitivity, imaging quality, and imaging capability. The one thing that makes these calibrations difficult is the need for working in vacuum substantially extending the required time and effort compared to visible systems. In theory a ray tracing and characterization of each individual component of the optical system (mirrors, windows, grating) should provide the transmission efficiency of the combined system, but potential unknown effects (contamination, misalignment, measurement errors) will make the final error too large for most applications. Therefore it is desirable to test and measure the optical properties of the whole system in vacuum and compare the overall response to the response of a calibrated photon detector. Based on the experience with the IMAGE Spectrographic Imager (SI) and Wide-band Imaging Camera (WIC), and the ICON-FUV instrument we will discuss the steps and procedures for the proper radiometric sensitivity and pass-band calibration, spot size, imaging distortions, flat field and field of view determination.

17.a.2 15:30 - 15:45: Neerav Shah: Enabling Revolutionary Science with a Virtual Telescope: Formation Flying Technologies and Capabilities

- NASA GSFC

Co-author(s): Joe Davila
- NASA GSFC

Significant new discoveries in space science can be realized by replacing the traditional large monolithic space telescopes with precision formation flying spacecraft to form a "virtual telescope." Such virtual telescopes will revolutionize occulting imaging systems, provide images of the Sun, accretion disks, and other astronomical objects with unprecedented milli-arcsecond resolution (several orders of magnitude beyond current capability). This enabling technology can also be used for interferometric imagers, exoplanet hunters, and black hole imagers. Since the days of Apollo, NASA and other organizations have been conducting formation flying in space, but not with the precision required for virtual telescopes. These efforts have focused on rendezvous and docking (e.g., crew docking, satellite servicing, etc.) and/or ground-controlled coordinated flight (e.g., EO-1, GRAIL, MMS, etc.). Although proposed, no organization has flown two spacecraft in a coordinated fashion to form a virtual science instrument capable of imaging distant phenomena.

We will discuss the state of the art in precision formation flying capabilities, the technology gaps, and plans for advancing towards a full scale virtual telescope mission.

17.a.3 15:45 - 16:00: Dong Wu: Development of low-power 2.0 THz heterodyne spectrometer to profile global lower-thermospheric wind, temperature and atomic oxygen density

- NASA GSFC

Co-author(s): Jeng-Hwa Yee[1], Erich Schlecht[2], Imran Mehdi[2], Robert DeMajistre[1]
- [1]John Hopkins University APL, [2]NASA JPL

Lower thermospheric neutral winds are the critical measurements needed to better understand complex electrodynamic processes in ion-neutral interactions and their impacts on the composition and structure of the ionosphere. We are developing a high-sensitivity and low power heterodyne spectrometer at 2.0 THz to measure neutral winds, temperature and atomic oxygen (O) density profiles at 100-150 km altitudes using the limb sounding technique from space. This THz Limb Sounder (TLS) instrument, supported under NASA's Geospace Instrument Development and Enabling Science Program (GIDES), leverages the rapidly-improved sensitivity of heterodyne receiver technology to resolve the wind-induced Doppler shift in the O emission at 100-200 km altitudes. A similar Doppler wind sounding technique has been achieved at lower altitudes using the 118-GHz O2 [Wu et al., 2008] and 625 GHz (O3 and HCl) [Baron et al., 2013] emission lines. At a higher frequency, TLS can be miniaturized as a low-mass and low-power sensor that fits within CubeSat and SmallSat platforms. By providing continuous day-night measurements from the O emission, TLS will fill a critical data gap in the dynamo region where the understanding of the coupling between charged and neutral particles is hindered by poor local time sampling and insufficient accuracy in global wind observations.

17.a.4 16:00 - 16:15: Luciano Rodriguez: ASPIICS, a Giant Solar Coronagraph Onboard the PROBA-3 Mission

- Royal Observatory of Belgium

Co-author(s): Zhukov Andrei, Rodriguez Luciano, PROBA3-ASPIICS team
- Royal Observatory of Belgium

PROBA-3 is the next ESA mission in the PROBA line. Its main goal is in-orbit demonstration of formation flying technologies. PROBA-3 will consist of two spacecraft together forming a giant coronagraph called ASPIICS (Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun). The main spacecraft will host the telescope, and the other one will carry the external occulter of the coronagraph. ASPIICS heralds the next generation of coronagraphs for solar research, exploiting formation flying to gain access to the inner corona under eclipse-like conditions for long periods of time. The PROBA-3 mission profile will be reviewed, the ASPIICS instrument design will be described, and the scientific objectives of the mission will be discussed.

17.a.5 16:15 - 16:30: Amir Caspi: Enabling Technologies for Solar X-ray Observations from CubeSats

- Southwest Research Institute

Co-author(s): Albert Y. Shih[1], Harry P. Warren[2], Thomas N. Woods[3], Andrew Jones[3]
- [1]NASA GSFC, [2]Naval Research Laboratory, [3]University of Colorado LASP

Solar X-ray observations provide important diagnostics of plasma heating and particle acceleration, particularly during solar flares. Spectrally- and temporally-resolved measurements are crucial for understanding these energetic processes, as well as the Earth ionospheric dynamics driven by solar X-ray loading on the upper atmosphere. Traditionally, solar X-ray observations have been made using sizable, massive, and/or power-hungry instruments requiring large, expensive satellites (e.g., Explorers). Sounding rockets and long-duration balloons provide lower-cost access to space but the former provide very short observing windows, while the latter restrict observations to only hard X-rays $>\sim$30 keV due to atmospheric absorption. Recently, new technologies have emerged that make solar soft and hard X-ray observations feasible from a low-cost orbital platform: CubeSats. These include miniaturized, low-noise, low-power X-ray detectors such as the Amptek X123, using a silicon drift detector to provide $\sim$0.15 keV FWHM resolution from $\sim$0.5 to 30 keV and a cadmium telluride detector to provide $\sim$1 keV FWHM resolution from $\sim$5 to 100 keV. Solar-pointed CubeSats are enabled by advances in support subsystems such as miniaturized high-precision attitude determination and control systems and high-bandwidth communications. We present solar soft X-ray spectra from the Amptek X123-SDD, flown on two SDO/EVE calibration sounding rocket underflights in 2012 and 2013, and discuss plans to space-qualify the Amptek X123-CdTe. The X123-SDD will fly on the upcoming Miniature X-ray Solar Spectrometer (MinXSS) CubeSat, scheduled for deployment from the ISS in mid-2015. We also present a novel spectro-spatial imager concept, prototyped on the 2013 rocket flight. This imager and the two Amptek spectrometers comprise the instrument suite proposed for the CubeSat Imaging X-ray Solar Spectrometer (CubIXSS), a 6U CubeSat to observe soft and hard X-ray emission, from $\sim$0.12 keV up to $\sim$100 keV, from solar flares and the quiescent Sun over a 1-year nominal mission.

17.a.6 16:30 - 16:45: Martin Fivian: Precise Aspect Systems for a Sun-Pointed Spin-Stabilized Spacecraft

- University of California - Berkeley

Co-author(s): Säm Krucker
- University of California - Berkeley

Requirements and implementations for a precise aspect system are discussed based on the experience of RHESSI. The RHESSI satellite is a spin-stabilized, sun-pointed instrument which provides solar imaging spectroscopy in the hard X-ray and gamma-ray regime. With its rotating modulating collimators it images the Sun indirectly. The reconstructed images have a resolution of 2 arcsec and the location on the solar disk is known on a sub-arcsec level. This requires a precise aspect system containing of two sensors, the Solar Aspect System (SAS) and the Roll Angle System (RAS). The solar aspect system consists of three lenses focusing a narrow bandwidth image in the red continuum onto three linear CCDs. It provides the knowledge of the pointing of the telescope with respect to the location of the Sun. RHESSI has two redundant roll angle systems, a PMT based and a CCD based instrument. Both systems measure accurately the timing of the passing of a focused image of a star over the sensor providing the roll angle of the satellite with respect to the star field. Besides the requirements and implementations, we discuss calibration and performance of such aspect systems. We will also present some limitations and possible scaling for future missions.

17.a.7 16:45 - 17:00: Joseph Plowman: The CoMP Instrument and Data Processing

- NCAR High Altitude Observatory

Co-author(s): Giuliana de Toma, Steven Tomczyk
- NCAR High Altitude Observatory

I present an overview of the Coronal Multichannel Polarimeter (CoMP), covering the general properties of the instrument, its sensitivity to solar phenomena of interest, and sources of error and uncertainty in its data. I also show some updated results and processing of the data, which includes improved coalignment and updated calibration (flat-fielding, dark subtraction, and polarization cross-talk) of the data. The ultimate goal of this processing is to more clearly resolve the linear polarization signal (especially of the weaker 10798 Angstrom line) in the data, eventually resolving the Stokes V signal (in the 10747 line, at least) as well.

17.b Particles – New Techniques [Center]

Chair(s): N. Paschalidis, M. Hill

17.b.1 15:15 - 15:36: Justin Kasper: Design of a Sun-Facing Plasma Instrument for Solar Probe Plus

- University of Michigan

One of the instruments in the SWEAP thermal plasma instrument suite on the NASA Solar Probe Plus mission is a Sun-facing Faraday Cup known as the Solar Probe Cup (SPC). In order to capture the smallest ion scales at closest approach below 10 solar radii SPC is able to measure weak currents at more than 100 Hz, more than eight times faster than the related instrument on the recently launched DSCOVR mission. In addition to its high cadence, SPC must also survive the extreme photon and thermal environment of closest approach, with sunlight more than four hundred times levels at 1 AU, and temperatures of components exceeding a thousand degrees Celsius during operation. This talk will highlight some of the technical challenges behind designing SPC, with a focus on how the thermal, mechanical, electrical, and optical requirements for the instrument influenced materials selection and design, and how test facilities were developed to reproduce driving aspects of the near-Sun plasma and photon environment.

17.b.2 15:36 - 15:48: Ulrik Gliese: Improved Detection System Description and New Method for Accurate Calibration of Micro-Channel Plate based Instruments and its use in the Fast Plasma Investigation on NASA's Magnetospheric MultiScale Mission

- SGT, INC. at NASA GSFC

Co-author(s): L.A. Avanov[1], A.C. Barrie[2], J.T. Kujawski[3], A.J. Mariano[4], C.J. Tucker[5], D.J. Chornay[1], N.T. Cao[6], D.J. Gershman[7], J.C. Dorelli[4], M.A. Zeuch[8], C.J. Pollock[4], A.D. Jacques[4]
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The Fast Plasma Investigation (FPI) on NASA's Magnetospheric MultiScale (MMS) mission employs 16 Dual Electron Spectrometers (DESs) and 16 Dual Ion Spectrometers (DISs) with 4 of each type on each of 4 spacecraft to enable fast (30 ms for electrons; 150 ms for ions) and spatially differentiated measurements of the full 3D particle velocity distributions. This approach presents a new and challenging aspect to the calibration and operation of these instruments on ground and in flight. The response uniformity, the reliability of their calibration and the approach to handling any temporal evolution of these calibrated characteristics all assume enhanced importance in this application, where we attempt to understand the meaning of particle distributions within the ion and electron diffusion regions of magnetically reconnecting plasmas.

Traditionally, the micro-channel plate (MCP) based detection systems for electrostatic particle spectrometers have been calibrated using the plateau curve technique. In this, a fixed detection threshold is set. The detection system count rate is then measured as a function of MCP voltage to determine the MCP voltage that ensures the count rate has reached a constant value independent of further variation in the MCP voltage. This is achieved when most of the MCP pulse height distribution (PHD) is located at higher values (larger pulses) than the detection system discrimination threshold. This method is adequate in single-channel detection systems and in multi-channel detection systems with very low crosstalk between channels. However, in dense multi-channel systems, it can be inadequate. Furthermore, it fails to fully describe the behavior of the detection system and individually characterize each of its fundamental parameters.

To improve this situation, we have developed a detailed phenomenological description of the detection system, its behavior and its signal, crosstalk and noise sources. Based on this, we have devised a new detection system calibration method that enables accurate and repeatable measurement and calibration of MCP gain, MCP efficiency, signal loss due to variation in gain and efficiency, crosstalk from effects both above and below the MCP, noise margin, and stability margin in one single measurement. More precise calibration is highly desirable as the instruments will produce higher quality raw data that will require less post-acquisition data correction using results from in-flight pitch angle distribution measurements and ground calibration measurements. The detection system description and the fundamental concepts of this new calibration method, named threshold scan, will be presented. It will be shown how to derive all the individual detection system parameters and how to choose the optimum detection system operating point. This new method has been successfully applied to achieve a highly accurate calibration of the DESs and DISs of the MMS mission. The practical application of the method will be presented together with the achieved calibration results and their significance. Finally, it will be shown that, with further detailed modeling, this method can be extended for use in flight to achieve and maintain a highly accurate detection system calibration across a large number of instruments during the mission.

17.b.3 15:48 - 16:00: Daniel Gershman: The Parameterization of Top-Hat Particle Sensors with Microchannel-Plate-Based Detection Systems and its Application to the Fast Plasma Investigation on NASA's Magnetospheric MultiScale Mission

- *NASA GSFC*

Co-author(s): Ulrik Gliese[1], John C. Dorelli[2], Levon A. Avanov[3], Alexander C. Barrie[4], Dennis J. Chornay[3], Elizabeth A. MacDonald[2], Matthew P. Holland[2], Craig J. Pollock[2]

- [1]*SGT Inc,* [2]*NASA GSFC,* [3]*University of Maryland,* [4]*Millenium Engineering and Integration Company*

The most common instrument for low energy plasmas consists of a top-hat electrostatic analyzer geometry coupled with a microchannel-plate (MCP)-based detection system. While the electrostatic optics for such sensors are readily simulated and parameterized during the laboratory calibration process, the detection system is often less well characterized. Furthermore, due to finite resources, for large sensor suites such as the Fast Plasma Investigation (FPI) on NASAÕs Magnetospheric Multiscale (MMS) mission, calibration data are increasingly sparse. Measurements must be interpolated and extrapolated to understand instrument behavior for untestable operating modes and yet sensor inter-calibration is critical to mission success. To characterize instruments from a minimal set of parameters we have developed the first comprehensive mathematical description of both sensor electrostatic optics and particle detection systems. We include effects of MCP efficiency, gain, scattering, capacitive crosstalk, and charge cloud spreading at the detector output. Our parameterization enables the interpolation and extrapolation of instrument response to all relevant particle energies, detector high voltage settings, and polar angles from a small set of calibration data. We apply this model to the 32 sensor heads in the Dual Electron Sensor (DES) and 32 sensor heads in the Dual Ion Sensor (DIS) instruments on the 4 MMS observatories and use least squares fitting of calibration data to extract all key instrument parameters. Parameters that will evolve in flight, namely MCP gain, will be determined daily through application of this model to specifically tailored in-flight calibration activities, providing a robust characterization of sensor suite performance throughout mission lifetime. Beyond FPI, our model provides a valuable framework for the simulation and evaluation of future detection system designs and can be used to maximize instrument understanding with minimal calibration resources.

17.b.4 16:00 - 16:12: Alexander Barrie: Performance of a Discrete Wavelet Transform for Compressing Plasma Count Data and its Application to the Fast Plasma Investigation on NASA's Magnetospheric Multiscale Mission

- *NASA GSFC & Millennium Engineering and Integration*

Co-author(s): Penshu Yeh[1], John C Dorelli[1], George B Clark[1,2], William R Paterson[1], Mark L Adrian[1], Mathew P Holland[1], James V Lobell[1],

David G Simpson[1], Craig J Pollock[1], Thomas E Moore[1]
- [1]*NASA GSFC,* [2]*Catholic University of America*

Plasma measurements in space are becoming increasingly faster, higher resolution, and distributed over multiple instruments. As raw data generation rates can exceed available data transfer bandwidth, data compression is becoming a critical design component. Data compression has been a staple of imaging instruments for years, but only recently have plasma measurement designers become interested in high performance data compression. Missions will often use a simple lossless compression technique yielding compression ratios of $\sim$ 2:1, however future missions may require compression ratios upwards of 10:1. This study aims to explore how a Discrete Wavelet Transform combined with a Bit Plane Encoder (DWT/BPE), implemented via a CCSDS standard, can be used effectively to compress count information common to plasma measurements to high compression ratios while maintaining little or no compression error. The compression ASIC used for the Fast Plasma Investigation (FPI) on board the Magnetospheric Multiscale mission (MMS) is used for this study. Plasma count data from multiple sources is examined: resampled data from previous missions, randomly generated data from distribution functions, and simulations of expected regimes. These are run through the compression routines with various parameters to yield the greatest possible compression ratio while maintaining little or no error, the latter indicates that fully lossless compression is obtained. Finally, recommendations are made for future missions as to what can be achieved when compressing plasma count data and how best to do so.

17.b.5 16:12 - 16:24: Mark Popecki: Next Generation Microchannel Plates using Glass Capillary Arrays with Atomic Layer Deposition Films for Resistance and Gain

- *Incom, Inc.*

Co-author(s): M.J. Minot[1], D.C. Bennis[1], C.A. Craven[1], J.M. Renaud[1], A. O'Mahony[1], O.H.W. Siegmund[2], A.U. Mane[3], J. W. Elam[3]
- [1]*Incom, Inc.,* [2]*U.C. Berkeley,* [3]*Argonne National Laboratory*

"Next generation" microchannel plate (MCP) performance will be presented, demonstrating the unique suitability of these MCPs for future instrumentation. These attributes include: a) stable high gain performance, b) large area (203 mm x 203 mm), c) mechanical robustness and d) exceedingly low background compared to conventional lead oxide based MCPs.

Conventional MCP electron multipliers are typically made with lead oxide based clad glass and etchable core structures that are drawn and fused together to form an array of micron-sized parallel fibers. Plates are sliced from these arrays. The cores are etched away, and the remaining channels are hydrogen fired to create the secondary emission and resistive properties. The glass used for this process contains potassium 40, which creates background pulses from radioactive decay.

A new "next generation" approach has been developed, in which glass capillaries are drawn and fused without cores. The secondary emission and resistive properties are established by applying thin films with the Atomic Layer Deposition (ALD) technique. The glass and the resistive and secondary emission materials can all be selected to both minimize potassium-40, and optimize gain and resistance. Aluminum oxide and magnesium oxide are available as secondary emissive coatings for ALD application. These materials can produce more secondary electrons per primary electron than traditional MCPs, resulting in a high gain. The ALD process also makes possible length to diameter (L/d) ratios of ten thousand or more, which allows great flexibility for MCP design, including MCPs suitable for neutron detection techniques.

Next generation MCPs are presently made by Incom Inc. in collaboration with Argonne National Laboratory, the University of Chicago and UC Berkeley. They are available for use as individual plates up to 203mm x 203mm in size. They have also been incorporated into an 8" MCP photomultiplier tube known as the LAPPDTM (Large Area Picosecond Photo Detector).

Curved MCPs are also under development at Incom, for applications including particle detection or UV spectrometry. Curved MCPs may be shaped to meet focusing requirements, or to make secondary electron detection more efficient, potentially reducing instrument volume and mass.

17.b.6 16:24 - 16:36: George Clark: Modeling the response of a top hat electrostatic analyzer in an external magnetic field: Experimental validation with the Juno JADE-E sensor

- *Catholic University of America*

Co-author(s): Frederic Allegrini[1,2], David J. McComas[1,2], Philippe Louarn[3], Craig J. Pollock[4]
- [1]*Southwest Research Institute,* [2]*University of Texas - San Antonio,* [3]*Research Institute in Astrophysics and Planetology,* [4]*NASA GSFC*

We investigate the response of an electrostatic analyzer (ESA) in the presence of a uniform magnetic field when the electron gyro-radii become comparable to the scale size of the analyzer. This occurs typically for energies around 1 keV and field strengths around 1 G. Through simulations and specially designed laboratory experiments with the Jovian Auroral Distribution Experiment – Electron (JADE-E) sensor, we characterized the energy response, the angular response, and the geometric factor. We developed semi-empirical relationships that can be used for spherical top hat ESAs. We present the model that covers an energy range between 0.1 keV and 5 keV with an external magnetic field magnitude between 0 G and 3 G. This model can be applied to top hat ESAs more generally.

17.b.7 16:36 - 16:48: Ruth Skoug: Wide Field-of-View Plasma Spectrometer

- *Los Alamos National Laboratory*

Co-author(s): Herbert Funsten[1], Ron Harper[1], Keith Kihara[1], Eberhard Mobius[2], Jonathan Bower[2]
- [1]*Los Alamos National Laboratory,* [2]*University of New Hampshire*

We present a fundamentally new type of space plasma spectrometer, the "2PS" Spectrometer, whose field-of-view is nearly 2π-sr using fewer resources than traditional methods. The enabling component is analogous to a pinhole camera having an electrostatic energy-angle filter at the image plane. Particle energy is selected with a tunable bias voltage applied to the filter plate relative to the pinhole aperture plate. For a given bias voltage, particles from different directions are focused to different locations, which are measured using a microchannel plate detector with a position-sensitive anode. Full energy and angle coverage are obtained using a single high voltage power supply, resulting in considerable resource savings and allowing measurements at faster times scales. We present laboratory prototype measurements and simulations demonstrating the instrument concept and discuss optimizations of the instrument design for application to space measurements.

17.b.8 16:48 - 17:00: Jörg-Micha Jahn: FPGA-based Time-Of-Flight Determination for Particle Instruments

- *Southwest Research Institute*

Co-author(s): Don E George[1], John Hanley[1], Scott Weidner[1], Ruth Skoug[2], Herb Funsten[2], Elizabeth MacDonald[3], Brian Larsen[2]
- [1]*Southwest Research Institute,* [2]*Los Alamos National Laboratory,* [3]*NASA GSFC*

Determination of time-of-flight (TOF) is an important element of space plasma particle measurements. Nano-second timing is required to determine ion mass in time-of-flight instruments, or to determine position in position sensitive anode designs typically used in systems like top-hat electrostatic analyzers. With the increasing ubiquity of radiation hard field progammable gate arrays (FPGA), it is only natural to move TOF determination away from application specific integrated circuits (ASIC) to more general purpose, flexible FPGA-based systems. We discuss an example of a successful FPGA-based TOF system implemented in the two Van Allen Probes HOPE instruments. In each instrument, five parallel TOF circuits capable of processing 2 million events per second each at longest time-of-flight were implemented in a radiation hard RTAX2000 architecture. We discuss the performance, resource use, and advantages of this system, and will discuss the potential for future TOF technologies based on FPGAs.

17.c Fields – Spacecraft Charging [South]

Chair(s): K. Lynch, S. Califf

17.c.1 15:15 - 15:35, *Invited*: Harri Laakso: Space potential measurements with double probe technique

- *ESA*

We present an overview of the spacecraft potential measurement technique with double probe antenna. It is known that the spacecraft potential is often well correlated with the ambient electron density, which thus provides a simple tool to determine the density in tenuous plasma regions. We investigate the validity of this technique and aim to identify possible caveats and limitations in the usage of spacecraft potential as a density proxy. We have performed a large parametric study of spacecraft potential and density measurements from the Cluster spacecraft from a full solar cycle (years 2001-2012) by binning the data according to the solar UV flux, electron temperature and plasma regions. The density measurements are taken from the Whisper wave experiment that is operated both in active and natural mode. In active mode, a sounder is used to trigger the plasma resonances (Fuh, Fp), and in natural mode, natural plasma waves, particularly the lower cut-off of the plasma waves, are used to determine the electron density between 0.1-80/cc.

17.c.2 15:35 - 15:55, *Invited*: Christopher Cully: Spacecraft-plasma interactions: simulating instrument performance near a charged spacecraft

- *University of Calgary*

Co-author(s): Christopher Cully, Anders Eriksson, Milan Maksimovic, Douglas Rowland
- *University of Calgary, Swedish Institute of Space Physics, LPP CNRS, NASA GSFC*

The electrostatic environment near a real spacecraft can differ markedly from the ideal free-space environment in which many instruments perform best. Spacecraft charging impacts measurements on a variety of instruments, most notably those designed to measure DC electric fields and/or low-energy particles. The past decade has seen the growth of simulation codes that can quantify how spacecraft charging affects measured parameters. Although no one simulation technique is completely self-sufficient, it is possible to quantify expected instrument performance by combining the strengths of several different approaches.

We present the relative strengths and weaknesses of several simulation techniques (particle-in-cell, iterative particle tracing, boundary element method) in modelling low-energy particle and electric field instrument performance. The various models are applied to spacecraft to quantify expected instrument performance. We choose spacecraft in a variety several different plasma environments: Earth's ionosphere, Earth's magnetosphere, the solar wind and Jupiter's magnetosphere. Simulated effects of the spacecraft wake are included in most cases, as is the effect of non-conductive surfaces on the spacecraft. Where possible, we compare to real data to validate the simulation results.

17.c.3 15:55 - 16:10: Sam Califf: Double-probe electric field measurements in the inner magnetosphere from THEMIS: quantifying the effect of variable boom shorting on the electric field estimate

- *University of Colorado LASP*

Co-author(s): Sam Califf, Xinlin Li, Allison Jaynes, Quintin Schiller, Hong Zhao
- *University of Colorado LASP*

The ability to measure the quasi-static electric field is critical to understanding the dynamics of plasma in the Earth's magnetosphere. The electric field is responsible for convecting plasmasheet particles into the inner magnetosphere where they form the ring current. Additionally, the low-energy ($\sim$1 eV) particles in the plasmasphere are directly controlled by the near-DC component of the electric field. The shape of the plasmasphere in turn affects the higher energy ($>$ 500 keV) radiation belt electrons; the plasmapause defines the boundary between chorus waves (outside) that can energize radiation belt electrons to MeV energies, and plasmaspheric hiss (inside) that scatters radiation belt electrons into the loss cone. Here we focus on some of the challenges associated with making reliable measurements of the quasi-static electric field in the inner magnetosphere using the double-probe technique. We provide an overview of the basics of the double-probe instrument, and discuss errors due to photoemission from the spacecraft, electrostatic wakes, boom shorting and the conversion from the moving frame of the spacecraft into a physically relevant coordinate system. Finally, we use four years of THEMIS data to estimate the boom shorting factor as a function of spacecraft potential, and discuss the impact of uncertainties in this shorting estimation on the average characteristics of the dawn-dusk electric field in the inner magnetosphere.

17.c.4 16:10 - 16:25: Joseph Minow: Techniques for Measuring Surface Potentials in Space

- *NASA MSFC*

Co-author(s): Linda Neergaard Parker
- *Jacobs Technology, ESSSA Group, NASA MSFC*

Materials exposed to the space plasma environment charge to a net potential relative to the ambient plasma. The charging process is due to differential currents to the material surface that results in a net surface charge density. While this process is termed "spacecraft surface charging" when applied to aerospace hardware, it also applies to the surfaces of astronomical objects in direct contact with the space plasma environment including a number of planetary bodies, asteroids, and dust particles. The ability to measure surface potentials is important to many techniques used in conducting fundamental heliospheric science, spacecraft engineering operations, and space technology development activities. This presentation provides a survey of current technologies used to measure surface potentials of spacecraft and planetary bodies with examples of their application to space science and technology programs.

17.c.5 16:25 - 16:45, *Invited*: Kristina Lynch: Observing auroral ionospheric plasma despite sheaths and other observational difficulties

- Dartmouth College

Co-author(s): K A Lynch[1], L Fisher[1], P Fernandes[1], R Clayton[1], M Zettergren[2], D Hampton[3]
- [1]*Dartmouth College,* [2]*ERAU,* [3]*University of Alaska - Fairbanks*

The low altitude nightside auroral ionosphere is the region in which magnetosphere-ionosphere coupling currents are closed. These spatially inhomogeneous and time varying volume currents are difficult to capture with *in situ* observations. Our understanding of M-I coupling systems is limited by our understanding of the actual structure of ionospheric current closure. We can progress by assimilating a variety of data sets – *in situ* magnetic and electric fields, *in situ* plasma observations, groundbased auroral imagery, neutral wind maps, and radar profiles – into increasingly capable ionospheric models. While each data set provides only a piece of the picture, the assimilation process allows optimal use of each piece.

An important step in progressing our *in situ* observations is making them multi-point, and therefore, low-resource. For thermal particle observations, one mitigating parameter in an otherwise difficult observation is the high densities of the lower ionosphere, allowing the use of low-gain (current-sensing rather than particle-counting) particle sensors. Our observational goal is to define the actual structure of ionospheric closure currents. This can be approached with a number of different measurement techniques, in tandem with an ionospheric model, since the closure currents need to follow the rules of electrodynamics and current continuity. Low resource current-sensing thermal plasma sensors such as retarding potential analyzers and drift meters can provide valuable measurements of plasma parameters, including density and plasma flow, without the need for high voltages or deployable boom systems.

In this presentation we review the substantial hurdles of viewing the thermal ionospheric plasma from a moving, charged, *in situ* platform. These include payload charging sheath energies comparable to or larger than the energy obtained from the ram velocities; the limited view obtained from even a large number of *in situ* observation points; and the high dynamic range of parameter space in the ionospheric E and F regions. Despite these difficulties, the advantages of these low-resource measurements, which can be reproduced on a number of *in situ* observation platforms, used in tandem with proper plasma physics interpretation of their signatures in the disturbed observing environment, and as part of an assimilated data set into an ionospheric model, can allow us to progress in our understanding of ionospheric structuring and its effects on auroral coupling.

17.c.6 16:45 - 17:00: Carl Siefring: Impedance and Langmuir Probe Measurements of Plasma Parameters and Application to Determining Plasma Potential

- Naval Research Laboratory

Co-author(s): (George Gatling[1], William Amatucci[1], David Blackwell[1], David Walker[2], Richard Fernsler[2], Christopher Compton[2]
- [1]*Naval Research Laboratory,* [2]*Sotera Defense Solutions Inc.*

Impedance and Langmuir probes are well established diagnostics for measuring plasma density and other plasma parameters. An impedance probe works by placing a small RF signal on a probe and sweeping the applied frequency. The AC voltage and current to the probe are measured to determine the probe impedance. Characteristics of the impedance curve Z(f) are associated with plasma parameters such as plasma frequency and thus plasma density. Langmuir probes apply a slowly sweeping DC bias voltage (V) to a probe and measure the current (I). And in this case, the shape of the I-V characteristic is used to determine plasma parameters. Measurement of plasma potential is possible with these techniques and the measurement of plasma potential on a probe can be important for determining the charge state of a spacecraft. In the impedance probe technique, plasma potential is monitored by adding a DC voltage to the applied AC. When the DC voltage is equal to the local plasma potential the AC Impedance Z(f) has a minimum because the sheath around the probe collapses. In a Langmuir probe the plasma potential is determined by an inflection point in the I-V characteristic. Langmuir probe measurements of plasma potential are notoriously unreliable; however this may be improved by application of a small AC signal to the DC bias sweep. We will discuss the theory of impedance probes and Langmuir probe, recent chamber measurements of plasma potential and the planned implementation for the CAREII sounding rocket to be launched in November of 2015.

This work was supported by the Naval Research Laboratory base program.

17:15 - 19:00: Posters – Ground, Fields [Lobby]

Chair(s): E. Zesta, P. Erickson, R. Pfaff, B. Anderson

See Section 22.a for Ground Poster abstracts.

See Section 22.b for Fields Poster abstracts.

Friday, April 24, 8:30 - 17:00

18 8:30 - 10:15: PLENARY – Technology Integration / Future Directions (#1) [Auditorium]

Chair(s): J. Spann

18.1 8:30 - 8:55, *Invited*: Jim L. Burch: Technology Integration/Future Directions—Perspectives from the Magnetosphere

- *Southwest Research Institute*

Future progress in magnetospheric physics will require coordinated in-situ measurements and imaging across all relevant scales from the microscale to the global scale combined with corresponding multi-scale models. A critical need is the ability to assimilate data into the models, as is done in meteorology, so that an accurate predictive capability can be developed. We are nowhere near this goal now despite the fact that essentially all of the experimental requirements are met while processing speed limitations prevent kinetic models from extending into the smallest scales with realistic mass ratios. But this problem will be solved in time. The key now, and the real challenge, is to reduce the cost of making multiscale measurements throughout the magnetosphere while retaining enough sophistication to make critical advances in understanding. For particle instrumentation fast-switching high-voltage systems have always been the challenge. For electric fields the achievement of accurate 3D measurements including the difficult magnetic-field aligned component is perhaps an even greater challenge. Image inversion of UV and neutral atom imaging of inherently three-dimensional plasma regimes, while made easier by multiple imaging platforms, is equally difficult. In this perspective some suggestions, hopefully illuminated by the presentations during the meeting, will be made with the idea of improving prospects for future advances in the field.

18.2 8:55 - 9:20, *Invited*: Rod Heelis: Regional Area Descriptions of Ionospheric and Thermospheric Dynamics

- *University of Texas Dallas*

As the Earth's space environment becomes ever more considered as a coupled system, then considerations of magnetosphere-solar wind interactions and magnetosphere–ionosphere-thermosphere interactions will be most revealing when all the component systems are observed together.

A recurring theme in all these areas of study will be the need to identify the spatial scales at which different physical mechanisms operate and the temporal variability that exists at the various important scales. Only with this information incorporated into models that provide a description of the coupling between scales, will a full understanding of the system be realized.

To move forward in the area of ionosphere thermosphere coupling will require the ability to almost continuously observe a fixed region of the ionosphere and thermosphere, and to describe the dynamics of the charged and neutral gases within the region as a function of altitude. We will discuss strategies for accomplishing this task and the technological developments that could be required.

18.3 9:20 - 9:45, *Invited*: Nathan Schwadron: Interstellar Mapping and Acceleration Probe (IMAP)

- *University of New Hampshire*

Co-author(s): Merav Opher[1], Justin Kasper[2], Dick Mewaldt[3], Eberhard Moebius[4], Harlan Spence[4], Thomas Zurbuchen[2]
- [1]*Boston University,* [2]*University of Michigan,* [3]*CalTech,* [4]*University of New Hampshire*

Our piece of cosmic real-estate, the heliosphere, is the domain of all human existence – an astrophysical case-history of the successful evolution of life in a habitable system. By exploring our global heliosphere and its myriad interactions, we develop key physical knowledge of the interstellar interactions that influence exoplanetary habitability as well as the distant history and destiny of our solar system and world. IBEX was the first mission to explore the global heliosphere and in concert with Voyager 1 and Voyager 2 is discovering a fundamentally new and uncharted physical domain of the outer heliosphere. In parallel, Cassini/INCA maps the global heliosphere at energies (∼5-55 keV) above those measured by IBEX. The enigmatic IBEX ribbon and the INCA belt were unanticipated discoveries demonstrating that much of what we know or think we understand about the outer heliosphere needs to be revised. The next quantum leap enabled by IMAP will open new windows on the frontier of Heliophysics at a time when the space environment is rapidly evolving. IMAP with 100 times the combined resolution and sensitivity of IBEX and INCA will discover the substructure of the IBEX ribbon and will reveal in unprecedented resolution global maps of our heliosphere. The remarkable synergy between IMAP, Voyager 1 and Voyager 2 will remain for at least the next decade as Voyager 1 pushes further into the interstellar domain and Voyager 2 moves through the heliosheath. Voyager 2 moves outward in the same region of sky covered by a portion of the IBEX ribbon. Voyager 2's plasma measurements will create singular opportunities for discovery in the context of IMAP's global measurements. IMAP, like ACE before it, will be a keystone of the Heliophysics System Observatory by providing comprehensive cosmic ray, energetic particle, pickup ion, suprathermal ion, neutral atom, solar wind, solar wind heavy ion, and magnetic field observations to diagnose the changing space environment and understand the fundamental origins of particle acceleration.

9:45 - 10:00: Panel/Audience Discussion

19 10:30 - 12:15: PLENARY – Technology Integration / Future Directions (#2) [Auditorium

Chair(s): T. Moore

19.1 10:15 - 10:40, *Invited*: Marc Cheung: Remote Sensing Challenges for Understanding Solar Magnetic Activity

- Lockheed Martin Solar and Astrophysics Laboratory

Multi-wavelength remote sensing observations from the current generation of solar missions have yielded important insights into physical processes underlying a diverse range of magnetic activity on the Sun. They are also facilitating the development of data-constrained and data-driven models of the thermal and magnetic structure of the solar atmosphere. In this presentation, we will discuss (1) the state-of-the-art techniques in data-constrained and data-driven modeling, (2) remote sensing capabilities needed to improve the models for quantitative comparisons with observations and for the prediction of solar drivers of space weather, and (3) informatics and computing capabilities needed to enable scientific discovery.

19.2 10:40 - 11:05, *Invited*: Joseph Davila: Future Directions in Solar Observations

- NASA GSFC

Nearly all space weather phenomena originate at the Sun when energy stored on the large scale in the magnetic field is released by dissipation at the smallest scales by reconnection or some other dissipative process. Examples include coronal heating, flares, and possibly even solar wind acceleration. Current solar remote sensing observations are far from observing at the scale of the dissipation. Solar Probe Plus and Solar Orbiter will help in this regard, but will still not resolve dissipation processes in the low corona.

There are also few observations of the coronal magnetic field. The field is the basic element responsible for energy storage in the corona, and the basic link between the Sun and other environments throughout the heliosphere.

In this talk I will focus on recent progress in the development of new observational techniques to address these and other challenges of solar observation

19.3 11:05 - 11:30, *Invited*: John C. Foster: Global Ground-Based Observations of Geospace and Beyond

- MIT Haystack Observatory

Measurements of EarthÕs ionosphere, thermosphere and lower atmosphere provide a multi-dimensional mirror of magnetospheric and space weather processes while those regions provide important input and feedback to the overlying spheres of geospace. Observational techniques in the coming decade will emphasize autonomous arrays of distributed instruments providing global real-time coverage enabling forecast, analysis and research. Economics will demand the development of multi-purpose instruments capable of supporting a wide range of users simultaneously. Innovative means of data collection, assimilation, modeling and integration with in situ observations will be required. The role and characteristics of large remote sensing facilities will be addressed.

This presentation will provide an overview of MTSSP Conference presentations, suggestions, and discussion directed toward ground-based measurement techniques and technology needed to advance the fields of solar and space physics in light of this vision of the development of an integrated, global, multi-user capability.

11:30 - 11:45: Panel/Audience Discussion & Meeting Wrap-up

20 13:15 - 17:00: Editorial Meeting [Center]

Meeting for the Editorial Board (conveners).

21 POSTERS: 17:15 - 19:00 – Tuesday, April 21

21.a Particles Posters [Lobby]

Tuesday, April 21, 2015 – 17:15 - 19:00
Chair(s): T. Moore, G. Collinson

21.a.1 Frederic Allegrini: Thin Carbon Foils: A Critical Subsystem for Plasma, Energetic Particle, and Energetic Neutral Atom Instruments in Space

- Southwest Research Institute

Co-author(s): Robert W. Ebert, Stephen Fuselier, George Nicolaou, David J. McComas

Thin carbon foils play a critical role in the time-of-flight (TOF) and charge conversion subsystems used in many of the plasma, energetic particle, and energetic neutral atom sensors developed for space. These instruments take advantage of properties of the particle-foil interaction: charge conversion of neutral atoms and/or secondary electron emission. This interaction also creates several adverse effects for the projectile exiting the foil, such as angular scattering and energy straggling, that usually act to reduce the sensitivity and overall performance of an instrument. The magnitude of these effects varies with the incident angle, energy, and mass of the incoming projectile and the foil thickness. The thinnest foils flown typically have a nominal thickness (as specified by the manufacturer) of $\sim$0.5 – 1 μg cm^{-2}. In this presentation, we will summarize several studies that have quantified the properties of ions exiting the thin carbon foil and discuss recent work on graphene foils, a promising new technology that may be capable of mitigating the undesirable effects associated with these interactions.

21.a.2 Laiola Andersson: Monitoring The Ionosphere

- University of Colorado LASP

Co-author(s): L. Andersson, R. E. Ergun, G. T. Delory, A. I. Eriksson, M. W. Morooka, C. M. Fowler, T. McEnulty, D. Andrews, T. Weber1

To understand the dynamics of the Ionosphere – Thermosphere interaction the electron density and the electron temperature are key quantities to measure. For the ionsopheric research preformed on the MAVEN mission a Langmuir Probe and Waves (LPW) instrument was develop for measuring these quantities. The LPW instrument started to operate in September 2014 providing key ionospheric information from our sister planet Mars. This presentation will present the instrument concept and show the quality of the measurement. The presentation will discuss the problems with interpreting a LP-sweep and how important the combination of the two measurements is to get an accurate product.

21.a.3 Levon Avanov: Results from Preconditioning of 50 Microchannel Plate Chevron Stacks and Extended Life Test of 2 Stacks for the Dual Electron Spectrometers of the Fast Plasma Investigation on NASA's Magnetospheric MultiScale Mission

- University of Maryland & NASA GSFC

Co-author(s): Albert Mariano, Craig Pollock, Ulrik Glise, Dennis Chornay, Corey Tucker, Alexandr Barrie, Darrel Smith, Arthur Jacques

A common and extremely important part of many detection systems for space borne plasma spectrometers is the microchannel plate (MCP) particle amplifier. A Chevron MCP stack composed of two MCPs is employed in each of the 2 sensor heads in the 16 Dual Electron Spectrometers (DESs) of the Fast plasma Investigation (FPI) on NASA's Magnetospheric MultiScale (MMS) mission. For the success of the mission, it is very important to provide a stable and well quantified performance of the MCP particle amplifiers in flight. The performance of the MCPs is defined by their ability to reliably and consistently amplify charged particles exiting from the electrostatic analyzer. It is well known that the gain of MCPs decreases rapidly in the initial period of mission life as a function of extracted charge. It is therefore necessary to occasionally increase the MCP Voltage during flight to maintain a constant MCP gain. To minimize this gain degradation effect, it is customary to precondition the MCP by extracting charge until the gain change decreases and starts to stabilize. This process was performed for the 50 MCP Chevron stacks procured for use in the DESs by extracting 0.1 C/cm2 of charge. We describe the applied preconditioning process and summarize the very extensive results achieved and trends observed from the preconditioning and characterization of such a large number of MCP Chevron stacks.

One of the important questions for the success of the mission is how long the MCP can retain a stable performance. The preconditioning process and associated characterization only provides MCP performance and behavior data within a very limited range of extracted charge. Therefore, we have performed an extended life test of two MCP Chevron stacks to investigate the long term behavior of both MCP gain and efficiency. During this test, we extracted ∼20 C/cm^2 of charge corresponding to approximately 16 years of mission life. It was fount that the MCP efficiency does not change. This is essential as an efficiency change cannot be re-calibrated during flight by changing any settings in the detection system. The MCP gain is found to exhibit some gain change from its preconditioning point out to about 1 C/cm2 of extracted charge after which it stabilizes and remains constant through the rest of the life test. The change observed from 0.1 out to 1 C/cm^2 can readily be compensated for by our in-flight detection system calibration method and the results from the life test provide important information about how often we should expect to have to adjust the MCP voltage to maintain a fixed MCP gain. To complement the preconditioning results, we present the detailed results from this extended life test.

21.a.4 Richard Balthazor: A plasma spectrometer designed for Low Earth Orbit - design variants and on-orbit results

- US Air Force Academy

Co-author(s): Matthew McHarg, Gabe Wilson, Adam Samlowski, Roy Taylor, Gregory Copeland, C. Lon Enloe

The Integrated Miniaturized Electrostatic Analyzer (IMESA) is an *in-situ* plasma spectrometer with low size (∼2500 cm^3), weight (∼1 kg) and power (∼2.5W). Both positive ion and electron energy spectra on Low Earth Orbit can be recorded near-simultaneously, from which can be derived plasma density, temperature, and spacecraft charging. The instrument has on-orbit adjustable gain. The instrument comes in two design variants. The first is optimized for either positive or negative plasmas. It operates similar to a retarding potential analyzer with no anomalous transparency, and has a dE/E ∼ 1% with no dependence on spacecraft charging. The second is optimized for measuring in a quasi-neutral plasma, physically separating the charge species with a transverse electric field; the dE/E is ∼ 7% and the dependency of the instrument response function on spacecraft charging is discussed. The latter variant has flown on several satellites. A modest number of IMESAs in different orbits have been demonstrated analytically to improve the accuracy of global assimilative ionospheric models. We present details of both designs, including SIMION analysis of the instrument response functions, and instrument raw and derived data products from the IMESA currently flying on the STPSat-3 mission.

21.a.5 Alexander Barrie: In Flight Calibration of the Magnetospheric Multisale Mission Fast Plasma Investigation

- NASA GSFC & Millennium Engineering and Integration

Co-author(s): Daniel J Gershman, Ulrik Gliese, John C Dorelli, Levon A Avanov, Chad L Salo, Corey J Tucker, Mathew P Holland, Craig J Pollock

The Fast Plasma Investigation (FPI) on the Magnetospheric Multiscale mission (MMS) combines data from eight spectrometers, each with four deflection states, into a single map of the sky. Any systematic discontinuity, artifact, noise source, etc. present in this map may be incorrectly interpreted as legitimate data and incorrect conclusions reached. For this reason it is desirable to have all spectrometers return the same output for a given input, and for this output to be low in noise sources or other errors. While many missions use statistical analyses of data to calibrate instruments in flight, this process is difficult with FPI for two reasons: 1. Only a small fraction of high resolution data is downloaded to the ground due to bandwidth limitations and 2: The data that is downloaded is, by definition, scientifically interesting and therefore not ideal for calibration. FPI uses a suite of new tools to calibrate in flight. A new method for detection system ground calibration has been developed involving sweeping the detection threshold to fully define the pulse height distribution. This method has now been extended for use in flight as a means to calibrate MCP voltage and threshold (together forming the operating point) of the Dual Electron Spectrometers (DES) and Dual Ion Spectrometers (DIS). A method of comparing higher energy data (which has low fractional voltage error) to lower energy data (which has a higher fractional voltage error) will be used to calibrate the high voltage outputs. Finally, a comparison of pitch angle distributions will be used to find remaining discrepancies among sensors.

21.a.6 Alexandre Cadu: Grazing incidence time-of-flight mass spectrometer: prototype results and possible improvements.

- Research Institute in Astrophysics and Planetology

Co-author(s): Pierre Devoto, Jean André Sauvaud, Philippe Louarn

Time of flight mass spectrometry is widely used to study space plasmas in planetary and solar missions. It provides information about the plasma physical and chemical properties by individual analysis of ions and statistical processing. However, scientific needs constantly rise and new performances are necessary to achieve a better understanding of space plasma mechanisms. A research and development project has been performed at IRAP to reduce the consumption of this kind of instruments and improve their resolution. We use Microchannel Plates (MCP) in a grazing incidence configuration to replace usual carbon foil for electron emission. We designed and built a complete spectrometer prototype to validate the entire instrument concept. We present the first experimental results, theoretical possibilities of improvements and application examples.

21.a.7 Alexandre Cadu: Space-borne signal processing and data compression for time-of-flight spectra.

- Research Institute in Astrophysics and Planetology

Co-author(s): Jérémie Moysan, Pierre Devoto

In the context of space plasma study, a large variety of information is necessary to understand physical processes, such as chemical composition. Time-of-flight spectra provided by an ion mass spectrometer represent a huge amount of data. Because of telemetry constraints during operation, only a small part of the information is downloaded to the ground after compression. We propose a simple compression algorithm which preserves a great part of the information about mass composition. The compression factor is at least of one order of magnitude. Once at the ground, the data set can be inverted with a non-ambiguous procedure which provides an accurate ion composition and a quantifiable error. The algorithm has already been tested on a FPGA target, with a really encouraging computing time, with respect to the instrument operation.

21.a.8 Alexandros Chasapis: *in situ* observations of electron heating and acceleration within thin current sheets in turbulent reconnection

- Laboratoire de Physique des Plasmas

Co-author(s): A. Retino, F. Sahraoui, A. Vaivads, Y. Khotyaintsev, D. Sundkvist, A. Greco, L. Sorriso-Valvo, P. Canu

We present one *in situ* study of electron acceleration and heating during turbulent reconnection. We use Cluster observations in turbulent plasma downstream of the Earth's quasi-parallel shock and we analyze measurements inside thin current sheets. The observed current sheets have thickness less than the proton inertial length and show evidence of ongoing reconnection. Multi-spacecraft measurements at high temporal resolution allow to study electron distributions and wave activity at different locations inside the diffusion region. We discuss the possible mechanisms of electron heating and acceleration and the role of thin current sheets for dissipation in turbulent reconnection.

21.a.9 Victoria Coffey: The Dual Ion Spectrometers and their Calibration for the Fast Plasma Investigation on NASA's Magnetospheric MultiScale Mission

- NASA MSFC

Co-author(s): Michael O. Chandler, Yoshifumi Saito, Shoichiro Yokota, Takanobu Omoto, Levon A. Avanov, Craig J. Pollock, Ulrik Gliese, Daniel J. Gershman, Dennis J. Chornay, Elizabeth A. MacDonald, George B. Clarke, Anne Diekmann, Arthur D. Jacques

The scientific target of NASAÕs Magnetospheric MultiScale (MMS) mission is to study the fundamentally important phenomenon of magnetic reconnection. Theoretical models of this process predict a small size (order of hundred kilometers) for the ion diffusion region where ions are demagnetized at the dayside magnetopause. This region may typically sweep over the spacecraft at relatively high speeds of 50 km/s requiring the Fast Plasma Investigation (FPI) instrument suite to have an extremely high time resolution for measurements of the 3D particle distribution functions. As part of the FPI on MMS, the Dual Ion Spectrometers (DISs) will provide fast (150 ms) 3D ion velocity distributions, from 10 eV/q to 30,000 eV/q, by combining the measurements from eight different spectrometers (packaged in four dual sets) on each MMS spacecraft. The response uniformity among the spectrometer set, the consistency and reliability of their calibration in both sensitivity and their phase space selectivity (energy and angle), and the approach to handling any temporal evolution of these calibrated characteristics all assume enhanced importance in this application. To illustrate these challenges and show how they were met, we present an overview of the FPI Dual Ion Spectrometer together with a description of the calibration system, the method of approach, the results, and the lessons learned. Due to the demanding requirements and the effort of calibrating 32 sensors over two years, a highly systematic and accurate method of calibration was required for measurement repeatability. We will discuss the steps taken to achieve the needed accuracy and repeatability across the flight units and the lessons learned. The resulting values for the analyzer constant, geometric factor, effective area, energy and angular accuracy and resolution, crosstalk, particle noise, and UV rejection, along with the flight unit-to-unit variation will be presented. The precise knowledge of the instrument performance will be discussed in light of the science requirements and the on orbit expectations.

21.a.10 Glyn Collinson: Developments towards a 5keV imaging plasma spectrometer.

- NASA GSFC

Co-author(s): Thomas Moore, David Durachka, David Olson, David Knudsen, Paul Rozmarynowski, Adrienne Beamer, Mark Wong, Jeffrey Klenzing

"Top Hat" plasma analyzers typically have modest azimuthal resolution (c.f. 10 degrees, for reasons of electronic practicality), and can only read out a single energy at a time, thereby requiring a swept voltage to sample a range of energies. True energy imaging of particle populations was achieved with the Freja Cold Plasma Analyzer [2], and at higher time and energy resolution on subsequent sounding rocket flights using a CCD-based detection scheme, but only at energies below 200 eV [3]. We present initial developments towards expanding the energy range of such a "Whalen" plasma analyzer so that it is capable of making observations of cold (<1eV) and high-energy (5keV) space plasmas at very high temporal and spatial resolution. As part of this work, we present simulations of our analyzer, and a new technique for the manufacture of electrostatic lenses, resulting in a spherical grid with a grid separation of 150 lines per inch, resulting in unprecedented fidelity in the electric field contours.

21.a.11 Ryan Davidson: Miniaturization of Time-of-Flight Mass Spectrometers for CubeSat Applications

- Utah State University

Co-author(s): Michelle Pyle, Charles Swenson, Erik Syrstad

Time-of-Flight mass spectrometry (TOFMS) is a well-established technique for determining the mass of plasma and/or neutral particles. Compared to other mass spectrometry techniques, TOFMS has several satellite-friendly characteristics. TOFMS requires no magnetic fields and no intrinsically heavy components while also being extremely flexible in mass range, resolution, and measurement frequency. These characteristics make TOFMS an attractive technique for implementation on a CubeSat platform. We discuss various techniques being investigated or utilized at Utah State University to adapt TOFMS to a CubeSat platform.

21.a.12 Pierre Devoto: IDEE, the energetic electron detector onboard TARANIS

- Research Institute in Astrophysics and Planetology CNRS

Co-author(s): J.-A. Sauvaud, L. Prech, G. Orttner, K.W. Wong, G.Roudil

IDEE (Instrument for the Detection of Energetic Electrons) is one of the instruments onboard TARANIS, a CNES microsatellite dedicated to the study of magnetosphere-ionosphere-atmosphere coupling via transient processes, to be launched in 2017. IDEE is designed to detect electrons from 70 keV to 4 MeV. IDEE is composed of Si (silicon) and CdTe (cadmium telluride) semiconductor detectors, a low power front end ASIC (Application Specific Integrated Circuit) and a dedicated DPU (Digital Processing Unit). IDEE has three main scientific objectives: determine the pitch-angle Distribution of Radiation Belt Electrons (wave particle interactions), characterize Lightning-induced Electron Precipitation (LEP) and Relativistic Runaway Electrons (RRE). The central sector of the silicon detector has a geometrical factor allowing its use in the South Atlantic anomaly. The Silicon detector has a geometrical factor of suitable for pitch angle measurement and LEP detection. The CdTe detector has a geometrical factor of 100 cm^2.sr, which is compatible with the fluxes expected for RREs. The electronics is able to detect LEPs (several seconds at 200keV) and RREs (5 to 50 ms above 500 keV). A STM model of the sensor has been developed and validated in vibrations, thermal vacuum and solar vacuum. An EM model has been built and tested. The flight model is being integrated and tested. We discuss the science requirements and the development progress of IDEE.

21.a.13 Chad Fish: Topside Ionospheric Sounder for CubeSats

- ASTRA

Co-author(s): C. Winkler, G. Crowley, M. Pilinski, I. Azeem, C. Swenson

This presentation will outline the design of a Topside Ionospheric Sounder (TIS) for CubeSats. In the same way that an ionosonde measures the ionospheric profile from the ground, a Topside Sounder measures the ionospheric profile from a location above the F-region peak. The TIS will address the need for increased space situational awareness and environmental monitoring by estimating electron density profiles in the topside of the ionosphere. The TIS will measure topside electron density profiles for plasma frequencies ranging from 0.89 MHz to 28.4 MHz below the satellite altitude. The precision of the measurement will be 5% or 10,000 p/cm^3. The TIS average power consumption will be below 10 W and a mass of less than 10 kg, so it is appropriate for a 6U Cubesat (or multiple of that size). The sounder will operate via a transmitted frequency sweep across the desired plasma frequencies which, upon reception, can be differenced to determine range and density information of the topside ionosphere. The velocity of the spacecraft necessitates careful balancing of range resolution and frequency knowledge requirements as well as novel processing techniques to correctly associate the return signal with the correct plasma frequency. TIS is being designed to provide a low cost, low mass spacecraft that can provide accurate topside profiles of the ionospheric electron density in order to further understanding of ionospheric structure and dynamic processes in the ionosphere.

21.a.14 Ulrik Gliese: The Dual Electron Spectrometers and their Calibration for the Fast Plasma Investigation on NASA's Magnetospheric MultiScale Mission

- SGT, Inc. & NASA GSFC

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The scientific target of NASA's Magnetospheric MultiScale (MMS) mission is to study the important phenomenon of magnetic reconnection. It is believed that the electron and ion diffusion regions hold the key to uncovering the fundamental processes of magnetic reconnection. The Fast Plasma Investigation (FPI) on MMS is designed to study the plasma electrons and ions with both high spatial and temporal resolution, in order to gain detailed knowledge about their behavior in these diffusion regions.

Theoretical models predict a small size for the ion diffusion region of about a hundred kilometers and an even smaller size for the electron diffusion region on the order of ten kilometers. To achieve a high spatial resolution, FPI employs 16 Dual Electron Spectrometers (DESs) and 16 Dual Ion Spectrometers (DISs) with 4 of each type on each of 4 spacecraft flying in a close tetrahedral formation. Each spectrometer instantaneously provides 180° of spacecraft polar angle view in 11.25° bins and sweeps over 45° of spacecraft azimuth angle view in 11.25° bins. This provides full sky coverage for each satellite independent of spin rate over an energy range rapidly sweeping from 10 eV to 30,000 eV.

Magnetic reconnection processes are fast and may typically sweep over the spacecraft at relatively high speeds of around 50 km/s. Therefore, FPI must have extremely high time resolution for measurements of the 3D particle distribution functions. The DES has been designed and implemented to perform particle flux measurements over its complete energy range and polar and azimuthal views, in just 30 ms. This is about 100 times faster than previous state-of-the-art particle spectrometers.

The approach of combining the measurements from eight different spectrometers (packaged in four dual sets) on each spacecraft to produce each complete 3D sky distribution presents a new and challenging aspect to the calibration and operation of the instruments. The response uniformity among the spectrometers, the consistency and reliability of their calibration in both sensitivity and phase space selectivity (energy and angle), and the approach to handling any temporal evolution of these calibrated characteristics all assume enhanced importance in this application.

We present an overview of the FPI DES together with a description of our calibration method and system, and a comprehensive review of the results from the ground calibration of 16 DES instruments. The results include analyzer constant, detection system operating point, geometric factor, crosstalk, noise, energy resolution, angular accuracy, angular resolution and UV rejection. It is shown that our calibration approach, which employs a new method for the detection system calibration, provides a more precise calibration and a more thorough knowledge of the instrument behavior and performance. Further, our two e-beam calibration systems are shown to produce excellent measurement repeatability. Finally, the results demonstrate a high level of performance consistency, with $\leq 6\%$ variation in geometric properties and $\leq 25\%$ variation in MCP efficiency, across the entire DES population suitable for measuring dynamics within electron diffusion regions.

21.a.15 Sarah Jones: A Compact Ion and Neutral Mass Spectrometer for the ExoCube Mission

- *NASA GSFC*

Co-author(s): N. Paschalidis, M. Rodriguez, E. Sittler, D. Chornay

Demand is high for *in situ* measurements of atmospheric neutral and ion composition and density, not only for studies of the dynamic ionosphere-theremosphere-mesosphere system but simply to define the steady state background atmospheric conditions. The ExoCube mission is designed to acquire global knowledge of *in-situ* densities of [H], [He], [O] and [H+], [He+], [O+] in the upper ionosphere and lower exosphere in combination with incoherent scatter radar ground stations distributed in the north polar region. The Heliophysic Division of GSFC has developed a compact Ion and Neutral Mass Spectrometer (INMS) for *in situ* measurements of ions and neutrals H, He, N, O, N2, O2 with M/dM of approximately 10 at an incoming energy range of 0-50eV. The INMS is based on front end optics, post acceleration, gated time of flight, ESA and CEM or MCP detectors. The compact sensor has a dual symmetric configuration with the ion and neutral sensor heads on opposite sides and with full electronics in the middle. The neutral front end optics includes thermionic emission ionization and ion blocking grids, and the ion front end optics includes spacecraft potential compensation grids. The electronics include front end, fast gating, HVPS, ionizer, TOF binning and full bi directional C&DH digital electronics. The data package includes 400 mass bins each for ions and neutrals and key housekeeping data for instrument health and calibration. The data sampling can be commanded as fast as 10 msec per frame (corresponding to $\sim$80 m spatial separation) in burst mode, and has significant onboard storage capability and data compression scheme. Experimental data from instrument testing with both ions and neutrals will be presented. This miniaturized instrument (1.5U) weighs only 560 g and requires nominal power of 1.6W.

21.a.16 Joseph Kujawski: Small form factor delay line implementation for small top hat plasma analyzers

- *Siena College*

Co-author(s): M. Adrian, M. Harrington, R. Carroll, S. Atkinson, M. Hickey, C.J. Pollock, A. Weatherwax

In-situ detection of plasma distribution function using very small top hat analyzers presents a significant challenge due to the requirement to maintain a small form factor in the detection system while still maintaining sufficient angular resolution. The traditional technique of increasing the number of anode to amplifier/detector signal chains reaches the limits of mechanical implementation quickly so if better than very coarse angular resolution is required, other techniques must be employed.

We developed a delay line implementation of the anode to amplifier/detector signal chain that uses a matched delay system and FPGA to decode the arrival location of each pulse. The combination of a matched delay line system feeding the results to an FPGA removes the requirement for a high frequency clock to measure the relative arrival times for each pair of signals. This approach has the dual benefit of requiring a limited amount of FPGA resources and does not require a fast clock, which reduces overall power dissipation from this subsystem. This paper describes the implementation of this technique, test results from various stages of the implementation, and theoretical limitations of the approach.

21.a.17 Joseph Kujawski: High Frequency Design Considerations for the Large Detector Number and Small Form Factor Dual Electron Spectrometer of the Fast Plasma Investigation on NASA's Magnetospheric MultiScale Mission

- Siena College

Co-author(s): J.T. Kujawski, U. Gliese, N.T. Cao, M.A. Zeuch, D. White, D.J. Chornay, J.V. Lobell, L.A. Avanov, A.C. Barrie, A.J. Mariano, C.J. Tucker, B. Piepgrass, C. Auletti, S. Weidner, A.D. Jacques, C.J. Pollock

Each half of the Dual Electron Spectrometer (DES) of the Fast Plasma Investigation (FPI) on NASA's Magnetospheric MultiScale (MMS) mission utilizes a microchannel plate Chevron stack feeding 16 separate detection channels each with a dedicated anode and amplifier/discriminator chip. The desire to detect events on a single channel with a temporal spacing of 100 ns and a fixed dead-time drove our decision to use an amplifier/discriminator with a very fast (GHz class) front end. Since the inherent frequency response of each pulse in the output of the DES microchannel plate system also has frequency components above a GHz, this produced a number of design constraints not normally expected in electronic systems operating at peak speeds of 10 MHz. Additional constraints are imposed by the geometry of the instrument requiring all 16 channels along with each anode and amplifier/discriminator to be packaged in a relatively small space.

We developed an electrical model for board level interactions between the detector channels to allow us to design a board topology which gave us the best detection sensitivity and lowest channel to channel crosstalk. The amplifier/discriminator output was designed to prevent the outputs from one channel from producing triggers on the inputs of other channels. A number of Radio Frequency design techniques were then applied to prevent signals from other subsystems (e.g. the high voltage power supply, command and data handling board, and Ultraviolet stimulation for the MCP) from generating false events. These techniques enabled us to operate the board at its highest sensitivity when operated in isolation and at very high sensitivity when placed into the overall system.

21.a.18 Benoit Lavraud: Correcting moments of *in situ* particle distribution functions for spacecraft electrostatic charging

- Research Institute in Astrophysics and Planetology CNRS & Université de Toulouse & Centre National d'Etudes Spatiales

Co-author(s): Davin Larson

We first introduce previous works on spacecraft electrostatic charging and its effects on particle measurements and the calculation of moments from distribution functions. We illustrate the fact that the lack of use, or misuse, of Liouville's theorem may lead to misinterpretations and inappropriate corrections to those effects. We emphasize in particular that its appropriate use naturally accounts for what is often called the "sheath focusing effect" in moments calculation. In the case of a "perfect" particle detector we show there exists a trivial and essentially exact formulation for the calculation of moments of particle distribution functions that accounts for the spacecraft potential. The main limitations, but that are not specific to this formulation, are inaccuracies in angle information (from blurring of acceptance angles at low energies or spacecraft-skimming trajectory effects) and those arising from the detector properties (resolution, cutoffs, photo-electrons, etc.). We discuss this correction in the context of previous works and remind that it primarily affects low energy measurements, and for populations whose temperature is comparable to the potential. This correction is thus most needed for regimes such as that of solar wind electrons.

21.a.19 Susan Lepri: Detecting negative ions onboard small satellites

- University of Michigan

Co-author(s): Jason Gilbert, Jim Raines, James Cutler, M. Panning

Recent measurements around planets and their satellites have shown that heavy ions, energetic neutral atoms, molecular ions and charged dust contain a wealth of information about the origin, evolution, and interaction of celestial bodies with the space environment. Using highly sensitive plasma instruments, positively charged heavy ions have been used to trace exospheric and surface composition of planets and satellites as well as the composition of interplanetary and interstellar dust. While positive ions dominate throughout the heliosphere, negative ions are also produced from surface interactions. In fact, laboratory experiments have shown that oxygen released from rocky surfaces is mostly negatively charged. Negative ions have been detected with plasma electron analyzers in several different environments (e.g. on Cassini), though more extensive studies have been challenging without specialized instrumentation. We discuss adaptation of the proven heritage of the Fast Imaging Plasma Spectrometer (FIPS) on MESSENGER for use on small platforms for the measurement of negative ions. MESSENGER/FIPS has been successfully measuring the plasma environment of Mercury since 2011 and has been used to map multiple ion species (H+ through Na+) throughout Mercury's space environment. Modifications to the existing design fits within the 6U CubeSat volume, and would provide a low mass, low power instrument, ideal for future Cubesat or distributed sensor missions seeking to characterize the contribution of negative ions throughout the heliosphere.

21.a.20 Nikolaos Paschalidis: Advanced Time of Flight, Position Sensing and Energy Measurement Technologies for Space Instrumentation.

- *NASA GSFC*

Time of flight, position sensing and energy measurements comprise a full set of measurements needed to define particle distribution functions including composition, in a broad range of instruments. The same is also true for several types of photon instruments. This talk will present a compact set of MCP, SSD, delay line, and ASIC technologies suitable for asynchronous/synchronous random event measurement and processing, with low dead time, high throughput, large dynamic range, high resolution and triple coincidence, properties enabling high quality science instrumentation. In the core of the methodology is a set of ASIC technologies with proven engineering robustness and quality in extreme space environments. This set of technologies has a flight record across the solar system on missions like Messenger and Pluto / New Horizons for two temperature extremes, JUNO and Van Allen Probes for high radiation environment, Cassini, IMAGE, IBEX, MMS and other future missions.

21.a.21 Michele Piana: RHESSI data and the use of averaged electron flux images for the quantitative study of acceleration and transport mechanisms in solar flares

- *Université di Genova*

Co-author(s): Anna Codispoti, A Gordon Emslie, Jingnan Guo, Anna Maria Massone, Michele Piana, Nicola Pinamonti, Gabriele Torre

Thanks to the highly resolved hard X-ray images provided by RHESSI data, imaging spectroscopy is in principle an effective tool for the study of the physical mechanisms underlying particle acceleration and transport in solar flares. On the other hand, the introduction of a regularized inversion technique for the spatially resolved bremsstrahlung equation (Piana et al. 2007), now allows the construction, at many different electron energies, of maps of the electron flux distribution, averaged along the line of sight and weighted with the column density. Torre et al. (2012) and A showed that these averaged electron flux images can be used for model selection among various candidates for the energy transport and particle acceleration mechanisms. More recently, Codispoti et al. (2013) studied the impact of the background drift velocity on the energy loss rate of accelerated electrons in the flare. Furthermore, in the works presented by Guo et al. (2012a, 2012b, 2013), both geometrical and physical properties of several loop-structured events are explored by means of the study of these electron maps, such as the acceleration region length, the total loop extent, the filling factor and the specific acceleration rate. This presentation is thus aimed at giving an extended overview of the contributions given to the quantitative study of solar flares by the introduction of the averaged electron flux images reconstructed from RHESSI observations.

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21.a.22 Amy Rager: Study of Dynamic Micro-Channel Plate Saturation Effects for the Fast Plasma Investigation Dual Electron Spectrometers on NASA's Magnetospheric MultiScale Mission

- NASA GSFC & Catholic University of America

Co-author(s): A.C. Rager, D.J. Chornay, C.J. Tucker, C.J. Pollock, L.A. Avanov, D.J. Gershman, A.C. Barrie, U. Gliese

We studied the onset of saturation in micro-channel plates (MCPs) under pulsed high flux for the MCPs used in the Dual Electron Spectrometers (DESs) of the Fast Plasma Investigation (FPI) on NASA's Magnetospheric MultiScale (MMS) mission. The results show that saturation is a function of both the exposure time of the MCP to the flux and the level of the incoming particle flux. Using a deflection gating technique we were able to rapidly pulse the exposure of high flux electrons to the MCP while allowing for re-charge of the MCP channels between pulses. We show that short exposure pulses coupled with a set deflection time can prevent saturation at very high particle flux. The results of this experiment bodes well for the MMS mission, where the time scale of incoming high flux beams may at times be short enough that we should not expect distortion by saturation effects. Finally, it is shown that our findings converge to the observed saturation effects under static flux conditions when we decrease the pulse rate of the incoming flux.

21.a.23 Jean Rubiella Romeo: Usage of the ceramic channeltrons in the extreme environment of the Solar Orbiter mission.

- Research Institute in Astrophysics and Planetology

Co-author(s): Philippe Rouger, Andrei Fedorov

Solar Orbiter is a future ESA mission developed to explore the interface region in the vicinity of the Sun. The orbit perihelion is 0.28 AU and the aphelion is between 1 and 0.8 AU. The mission duration will be at least 10 years.

The solar wind ion analyser PAS is the one of the keys instruments of the Solar Orbiter plasma package. It has to make a permanent measurements of the solar wind ion flux in the 0.2 – 20 keV/q energy and appropriate angular ranges.

One of the main challenge of the PAS instrument is a very large dynamic range of the particle flow. The instrument should provide fast and statistically correct measurements of the rather cold but containing scientifically important minor features ion distribution in any point of the satellite orbit. This requirement leads to need to have a detector than can accept at least 107 1/s events for each 6° angular channel. In addition the very harsh thermal environment of the mission brings very tight constraints on the detectors thermal control and lifetime. The temperature, indeed, will reach at maximum more than 400°C at the entrance of the instrument and around 65°C in the detector compartment. All such requirements motivated us to choose the ceramic channeltrons CEM) as instrument detectors. The main problem was if such CEMs can survive more than 10 years working permanently in such hard environment.

We have designed a special facility to make a lifetime test of the ceramic CEMs with various thermal conditions, and performed number of corresponding experiments. The experimental results show that the tested CEMs are still in good heals after accumulation at least 1013 events working permanently at 75°C that correspond to more than 20 years onboard of Solar Orbiter.

21.a.24 John Sample: Thin-window, Low-threshold, Solid State Detectors for Supra Thermal Particles.

- University of California - Berkeley

Co-author(s): Albert Shih, Craig Tindall, Olivier Limousin

At the Space Sciences Laboratory of the University of California, Berkeley (UCB/SSL) we have developed silicon semiconductor detectors (SSD) with thin windows and unusually low energy electronic thresholds, ∼1-2 keV rather than the usual ∼20-30 keV, for suprathermal particle measurements. These SSDs can provide much higher sensitivity and lower background than the electrostatic analyzers usually used in the ∼2-30 keV energy range, while requiring about an order of magnitude less resources – few cm size, ∼100 grams mass, ∼100s milliwatts power. The SSDs, such as those utilized in the STEREO-STE instrument, are made from high-resistivity silicon, featuring especially thin n-type contacts (Tindall et al., 2008), with a backside contact consisting of a 200 Å thick polysilicon layer plus a 200 Å aluminum layer. By utilizing state-of-the-art electronics, STE is able to detect electrons down to 2 keV with better than ∼1keV FWHM resolution. Each STE had four SSD pixels look through a rectangular opening that provides a ∼20 x ∼80 FWHM FOV per pixel, for a total FOV of ∼80x80 degrees and geometric factor of ∼0.2 cm2 ster (four times larger than WIND-EESAH). STE has a 100% duty cycle, which together with the higher sensitivity, provides a factor of >30 in effective signal as compared to EESA-H, with a background of ∼1 c/s vs EESA-H's ∼20c/s; thus signal to noise for STE is >1000 times greater than an ESA. The STE mass (including electronics) is ∼0.4kg, and power is ∼0.5 W, sensor size ∼5cm on a side.

These low threshold SSDs can easily be pixelated and read out in large arrays with the addition of low power ASIC electronics to enable orders of magnitude higher sensitivity and/or angular resolution both for imaging ENAs and X-rays. These detectors can be utilized in low resource instruments such as those found in cubesats or many modules can be combined to make a sensitive imaging detector. The STEIN detector developed for the CINEMA cubesats is complete at 400g, 5cmx10cmx10cm and 0.7W with 32 pixels and electrostatic deflection for sorting incoming particles by charge. Larger combinations of strip detectors can be combined with Fourier transform imaging (such as the technique used in the RHESSI mission). A proposed instrument development effort to take advantage of these detectors is the Solar Energetic Neutral-atom Imaging Coronagraph (SENIC), which would to observe ENAs from <∼20 keV to a few hundred keV with a spectral resolution as good as 1 keV and image them from 2 Rsun to 40 Rsun with an angular resolution of 0.1 Rsun.

21.a.25 Lois Sarno-Smith: Explaining the Loss of The High Energy (1-10 eV) Plasmasphere Population seen by the Van Allen Probes

- University of Michigan

Co-author(s): Michael Liemohn, Ruth Skoug, Brian Larsen, Geoff Reeves, John Wygant, Shasha Zou

The Van Allen Probes Helium Oxygen Proton Electron (HOPE) instrument measures the high energy tail of the thermal plasmasphere allowing study of topside ionosphere and inner magnetosphere coupling. Previously, an unexpected feature in the HOPE low energy ion data was found – a dearth of partial plasma density in the 1-10 eV population in the post-midnight sector near Earth (L-Shell < 3) during quiet periods. Further analysis of the HOPE pitch angle distributions and HOPE temperatures reveal the cause of the loss of plasma in the post-midnight sector and enhance our understanding of magnetosphere-ionosphere coupling.

21.a.26 Padmashri Suresh: Langmuir Probe Theory for Non-uniform Surface Potential

- Utah State University

Co-author(s): Charles Swenson

Langmuir probes are one of the most widely used techniques for measuring the *in-situ* temperature and density of the Ionosphere. Although simple to design, the accurate retrieval of temperature and density from the resulting current-voltage characteristics can be highly challenging. A non-uniformity of the probe surface resulting in variability of the probe to plasma potential across the sensor is one such problem that can make analysis highly challenging.

In this paper, we present a first principles based approach of dealing with surface potential non-uniformity. We present a current collection theory which describes the current measured by the probe under these conditions. We derive a set of current collection equations in the context of an Ionospheric plasma regime that would be encountered by a typical sounding rocket flight.

We also present a discussion of the implications of surface non-uniformity on the deductions of the density and temperature, and the applicability and necessity of this theory, by using data from multiple Langmuir probes on-board two different sounding rocket missions.

21.b Photons Posters [Lobby]

Tuesday, April 21, 2015 – 17:15 - 19:00
Chair(s): S. Christe, J. Davila

21.b.1 Natalie Foster: Calibration of high resolution silicon X-ray detectors for FOXSI

- University of Florida

Co-author(s): Juan-Camilo Buitrago-Casas, Lindsay Glesener, Shin-nosuke Ishikawa, Säm Krucker, Steven Christe

In order to produce high-sensitivity X-ray images of the Sun to investigate particle acceleration, high resolution, low-noise X-ray detectors must be calibrated to known emission spectra in the corresponding energy range. The Focusing Optics X-ray Solar Imager (FOXSI) is a sounding rocket project under NASA's Low Cost Access to Space program that uses direct focusing to image solar hard X-rays. The FOXSI-1 focal plane consists of seven DSSD's (double-sided silicon strip detectors) that were donated by the Astro-H group at ISAS/JAXA. FOXSI aims to image solar hard X-rays using direct focusing optics, rather than indirect techniques that have previously been used, to attain increased sensitivity. These detectors underwent a thorough calibration using radioactive isotopes with known X-ray emission lines, including Am-241, Ba-133, and Fe-55, with peaks in their spectra within FOXSI's energy range ($\sim$4-15 keV). Some of the calibrated detectors were flown on the second rocket payload, FOXSI-2, on December 11, 2014, along with two additional CdTe detectors to extend the high-energy part of the energy range to $\sim$20 keV.

21.b.2 Albert Shih: High-resolution imaging, spectroscopy, and polarimetry of solar gamma rays

- NASA GSFC

Co-author(s): Pascal Saint-Hilaire, Nicole A. Duncan, Gordon J. Hurford, Hiroyasu Tajima, Mark S. Amman

Recent technological developments enable significant advances in observations of the gamma-ray signatures of particle acceleration by solar flares. 3D position-sensitive germanium detectors (3D-GeDs) can record each energy deposition with an energy resolution of a few keV FWHM and a spatial resolution of $<$0.1 mm3. By reconstructing the Compton-scatter tracks in 3D-GeDs, the location of the initial interaction of each gamma ray can be determined, as well as the polarization of a gamma-ray source. A single multi-pitch rotating modulator (MPRM) can be placed in front of a set of such detectors to provide high-resolution and high-quality images via indirect imaging. The balloon-borne Gamma-Ray Imager/Polarimeter for Solar flares (GRIPS) instrument will be demonstrating this combination of technologies on an upcoming Antarctic long-duration balloon flight. GRIPS will observe flare gamma-ray/hard X-ray emission ($\sim$20 keV to $>\sim$10 MeV) with an unparalleled angular resolution at gamma-ray energies (12.5 arcsec FWHM), sufficient to separate 2.2 MeV footpoint sources for almost all flares.

21.b.3 Juan Camilo Buitrago Casas: Properties of grazing incidence Wolter-I optics for hard-X rays

- University of California - Berkeley

Co-author(s): Steven Christe, Lindsay Glesener, Säm Krucker, Robert Taylor, Brian Ramsey

Wolter configurations use paraboloid and hyperboloid mirrors to focus X-rays. In a Wolter-I system, rays first reflect at a grazing incidence angle on a paraboloid mirror and then on a hyperboloid mirror. Mirrors of different diameters can be nested together to build up greater collecting area.

The Focusing Optics X-ray Solar Imager (FOXSI) is a state-of-the-art direct focusing X-ray telescope designed to observe the Sun from 4 to 15 keV.. This experiment completed its second flight onboard a sounding rocket last December 11, 2014 from the White Sands Missile Range in New Mexico. FOXSI optics has a Wolter-I geometry and consist of iridium-coated nickel/cobalt mirrors. Those mirrors were made using a replication technique based on an almost "perfect" polished surface. This allows a very good spacial resolution. A total of seven optical modules were used for the flight. Five of them had seven shells and the other two had ten shells each.

We present on various properties of Wolter-I optics that are applicable to solar HXR observation, including ray-tracing simulations and angular resolution measurements of the FOXSI optics. Of particular interest for our scientific needs are the reflectivity vs photon energy, single-bounce ("ghost ray") patterns from sources outside the field of view, and the variation in point spread function for different source angles.

21.b.4 Marc Lessard: A Despun Auroral Imager (DAI) for spinning spacecraft

- University of New Hampshire

Co-author(s): Paul Riley, Bruce Fritz, Allison Jaynes, Sarah Jones, Brent Sadler

A Despun Auroral Imager (DAI) has been developed for use on sounding rockets (such as the launch of the Rocket Experiment for Neutral Upwelling 2 (RENU2) mission, which will be flown in late 2015) and other spinning spacecraft. The DAI acquires topside images of auroral forms that are "de-spun" in order to minimize the effects of image blurring from the spinning of the rocket payload. The despinning is achieved via a rotating platform within the imager upon which is mounted a frame-transfer EMCCD and supporting electronics. The despin rate is controlled via a closed-loop feedback system that uses input from a roll rate sensor on the payload deckplate. Data are then compressed via a new lossless compression algorithm in order to maximize data transfer. The RENU2 imager will be positioned to look afterward and will acquire 2D images of visible auroral emissions at 630 nm in the cusp region. Representing a significant advance in the imaging process, the EMCCD (electron-multiplied CCD) with associated electronics will utilize double-correlated sampling to aid in noise reduction and will also incorporate the use of a thermoelectric cooling (TEC) to minimize noise in the EMCCD. One particularly difficult challenge has been the removal of heat from the EMCCD because of the low conductivity associated with the rotating platform.

21.b.5 Neil Murphy: A compact Doppler/magnetic solar imager

- NASA JPL

Co-author(s): Stuart Jefferies, Marco Velli, Wayne Rodgers

Images of flows and magnetic fields in the photosphere and chromosphere provide a key measurement set, supporting continuing efforts to understand the evolution of solar activity and how it affects the heliosphere. Measurements from SOHO and SDO have provided great insights into the internal structure and dynamics of the sun and its magnetic activity, but are ultimately limited by their single field of view, covering less than 180 of longitude. Several missions have been proposed to expand this field of view by providing measurements separated from the earth in heliocentric longitude, and Solar Orbiter will be the first mission to accomplish this. To enable future missions to be accomplished with minimal resources, we have developed a compact Doppler/magnetograph, based on a magneto-optical filter (MOF). MOFs provide a stable wavelength reference and, due to their wide field of view, enable a compact optical system. We will describe several iterations of the Doppler/magnetograph design, targeted at different mission requirements, including an instrument that can be accommodated on an interplanetary CubeSat.

21.b.6 Gordon Hurford: Imaging Techniques for Solar Hard X-rays and Gamma-Rays

- Univerisity of Applied Sciences and Arts Northwestern Switzerland & University of California - Berkeley

Grid-based techniques for imaging solar hard X-rays and gamma rays are reviewed, comparing the strengths and weaknesses of time-and spatial-modulation; single mask, bigrid and multigrid configurations. The comparisons will include discussions of the differences in detector requirements, alignment requirements, imaging performance and sensitivity. Examples will include HInotori, SolarMax/HXIS, Yohkoh/HXT, RHESSI, STIX and GRIPS.

21.b.7 Seth Wieman: An Optics Free Spectrometer for Solar EUV Measurements: Initial Results and Planned Improvements

- University of Southern California

Co-author(s): Leonid Didkovsky

An Optics Free Spectrometer (OFS) for measuring solar EUV spectral irradiance was demonstrated on sounding rocket flight 36.289 in July 2014. The OFS obtains solar spectra through electron energy analysis of photoelectrons from ionization of a Neon target gas by incoming EUV photons. It does not use mirrors, reflective gratings or thin film filters, and is therefore not susceptible to the long-term degradation that these optical elements typically exhibit when used for space-based EUV measurements. OFS Spectra obtained during the flight were contaminated by significant background signal, well beyond the negligible background levels observed during testing and calibration of the OFS at the National Institute of Standards and Technology Synchrotron Ultraviolet Radiation Facility (NIST/SURF). We present our assessment of the most likely source of this signal contamination based on analyses of the flight data and post-flight laboratory tests performed with the OFS. Proposed OFS design modifications to eliminate the background signal on future OFS flights are also presented.

21.b.8 Derek Gardner: Ha Airglow Temperature Observations using Field-Widened Spatial Heterodyne Spectroscopy

- University of Wisconsin - Madison

Co-author(s): Ed Mierkiewicz, Fred Roesler, John Harlander, Susan Nossal

During 2013, a new, high resolution field-widened spatial heterodyne spectrometer (FW-SHS) uniquely designed to observe geocoronal Balmer-alpha emission ([Ha], 6563A) was installed at Pine Bluff Observatory (PBO) near Madison Wisconsin. FW-SHS observations were conducted to compare with an already well-characterized dual-etalon Fabry Perot Interferometer (FPI) optimized for [Ha], also at PBO. The FW-SHS is a robust new Fourier-transform instrument that combines a large throughput advantage (∼100x that of the FPI) with high spectral resolution and a relatively long spectral baseline (∼ 10x that of the FPI) in a compact, versatile instrument with no moving parts. Coincident [Ha] observations by FW-SHS and FPI were obtained over similar integration times, resolving power (∼80,000 at [Ha]) and field-of-view (1.8 and 1.4 degrees, respectively). This paper describes the FW-SHS first light performance, data analysis, and [Ha] observation results collected from observing nights across 2013 and 2014.

Initial FW-SHS observations of Balmer-alpha intensity and temperature (doppler width) vs. viewing geometry (shadow altitude) show close agreement with the geocoronal theory and observations previously obtained at PBO by FPI. FW-SHS noise introduced by the multiplex disadvantage, a constraint the FPI does not have, currently appears to limit the FW-SHS effectiveness at constraining sub-Rayleigh dynamic exosphere signatures and cascade- component contributions predicted to arise in the wings of the Balmer-alpha line profile at high shadow altitudes. However, the FW-SHS is still capable of determining geocoronal Balmer-alpha doppler shifts on the order of 100 m/s across a 640km/s [Ha] spectral bandpass, within a dynamic time scale on the order of minutes.

These characteristics make the FW-SHS well suited for spectroscopic studies of relatively faint, diffuse-source geocoronal Balmer-alpha emission from Earth's upper atmosphere (∼ 2-14R) and the interstellar medium in our Galaxy. Current and future observations expand long-term geocoronal hydrogen observation data sets already spanning two solar maximums.

21.b.9 Adrian Daw: Calibration of EUNIS 2013

- NASA GSFC

Co-author(s): Douglas Rabin

The Extreme Ultraviolet Normal Incidence Spectrograph (EUNIS) sounding rocket instrument is a two-channel imaging spectrograph that observed the solar corona and transition region on 23 April 2013 with broad spectral coverage (303-370 Å, 527-635 Å) and unprecedented dynamic range, including emission lines of ionization stages from He I to Fe XX, and thus a wide temperature range of 0.03 to 10 MK. Absolute radiometric calibration of the two channels is performed using a hollow cathode discharge lamp and NIST-calibrated AXUV-100G photodiode. The calibration and characterization of the EUNIS-2013 dataset is presented, including a technique using photon noise to determine the point spread function of the detectors, which are KBr microchannel plate intensifiers fiber-optically coupled to cooled active pixel sensors.

21.b.10 Qian Wu: Thermospheric Wind Observation Over Antarctica to Explore the Cusp Heating Effect

- NCAR

One of the most striking features discovered during the first HIWIND flight in June 2011 is the persistent equatorward wind at all local times just equatorward of the auroral oval [Wu et al, 2012]. The standard NCAR TIEGCM did not reproduce this feature. Instead it showed a strong poleward wind on the dayside. One possible source for the unexpected dayside equatorward winds is strong Joule heating near the cusp region driven by strong east-west IMF conditions [Knipp et al. 2011 and Li et al. 2011]. When the TIEGCM was modified with enhanced cusp heating close to what Knipp et al. [2011] reported, it did reproduce similar equatorward winds. The mystery is that the first HIWIND observation was made during what appears to be modest north, east, and radial IMF conditions. One way to verify the enhanced cusp heating is to make thermospheric wind observations on the poleward side. TIEGCM simulation shows that the enhanced cusp heating can increase the poleward wind on the poleward side of the cusp by ∼100 m/s compared to the TIEGCM run with no increased cusp heating. HIWIND is well suited for this kind of observation, because it drifts slowly with the stratospheric winds and scans different geomagnetic latitudes. A proposed HIWIND flight in Antarctica will cover both equatorward and poleward sides of the cusp and provide the necessary data set.

Another objective of the HIWIND mission is to understand inter-hemispheric differences in the polar cap thermospheric winds. HIWIND can provide summer time polar cap observations in one hemisphere, while ground based Fabry-Perot interferometers simultaneous measure winds in another. The lack of daytime thermospheric wind observation has left many uncertainties in theories and modeling results on the thermosphere-ionosphere coupling in the summer polar cap. The simultaneous winter and summer polar cap wind comparison can shed more light on this topic. Ion drift observations from SuperDARN and ionosondes in the southern hemisphere and incoherent scatter radars in the northern hemisphere and the NCAR TIEGCM model will all be used to understand the thermospheric wind observations. HIWIND has demonstrated that it can provide accurate localized all local time coverage needed for this kind of study.

21.b.11 Irfan Azeem: 2.06 Terahertz Radiometer Design for Thermospheric Wind Sounding

- ASTRA LLC.

Co-author(s): Geoff Crowley, Dong Wu, Erich Schlecht

Robust and compact instruments for measuring neutral winds are needed to understand and predict satellite drag, as well as ionospheric instabilities and gravity wave filtering in the upper atmosphere. Neutral winds are an important indicator of energy deposition into the thermosphere. As the need to understand and specify the coupled IT system becomes ever greater for both scientific and operational reasons, so does the need to comprehensively characterize neutral winds in the thermosphere. The ionosphere and upper atmosphere also play a major role in Air Force and DoD missions, including communications, navigation, surveillance, and satellite drag. Understanding how the ionosphere affects these DoD missions is tied in part to understanding its motion and variability. Thermospheric winds contribute significantly to the morphology and variability of the ionosphere. Despite the high priority placed upon thermospheric neutral winds by the space weather community and the DoD, our ability to make persistent and accurate wind measurements with high resolution, global coverage, and frequent sampling is extremely limited. Consequently, there exists a critical and urgent need to develop new instruments capable of providing vector thermospheric neutral winds in Low Earth Orbit (LEO) under all solar and magnetic conditions.

We will review the design a novel miniaturized neutral wind instrument to measure vector winds in Low Earth Orbit (LEO) under all solar and magnetic conditions. The instrument design is based on a submillimeter wave remote sensing of the 2.06 THz oxygen line emissions from the thermosphere region. Because the 2.06 and 4.7 THz spectral features are two of the brightest line emissions in the terrestrial thermosphere, the THz heterodyne technique is the most technologically feasible remote sensing approach to meet the low volume, low power, low mass, and low risk requirements for future space weather missions. Rapid advances in sensor technology have led to significant miniaturization of components and power reductions, which have been exploited in the current instrument design to develop a cutting-edge new sensor for sub-millimeter wave remote sensing from CubeSat platforms for thermospheric neutral wind observations. The instrument, which we are calling THOR (2.06 THz Oxygen-line Radiometer),, initially funded by the Air Force SBIR program, will provide an unprecedented capability for measuring day and night thermospheric winds in the 90-150 km region, a capability not afforded by instruments operating in the visible or near-infrared wavelengths (e.g. Fabry-Perot Spectrometers or Interferometers). In addition, the limb-sounding capability of THOR will allow vertical profiling of neutral winds, thereby providing vertical coverage not afforded by any *in situ* measurements. This is a key advantage of the THOR instrument design over an *in situ* instrument. The THOR instrument, with additional processing of the signal, is also capable of providing high precision temperature and atomic oxygen [OI] density measurements to a higher altitude (∼300 km) than the wind profile. We will review Doppler sensitivity of the radiometer at 2.06 THz for determining the expected accuracy of the retrieved winds, provide a comprehensive technology assessment of THz receivers, and describe the design of a THOR instrument for CubeSat missions.

21.b.12 Brian Dennis: Diffractive X-ray Optics for Solar Flare Imaging

- NASA GSFC

Co-author(s): Gerald K. Skinner, Mary Li, Albert Y. Shih

We describe the design, fabrication, and testing of phase zone plate X-ray lenses with focal lengths of ∼100 m that are capable of achieving better than 0.1 arcsec angular resolution at energies around 1-10 keV. Such lenses could be included on a two-spacecraft formation-SSying mission with the lenses on the spacecraft closest to the Sun and an X-ray imaging array on the second spacecraft in the focal plane ∼100 m away. High resolution X-ray images would be obtained by aligning the two spacecraft with a region of interest on the Sun. Requirements and constraints for the control of the two spacecraft are discussed together with the overall feasibility of such a formation-SSying mission.

21.b.13 Brian Ramsey: Differential Deposition for Figure Correction in X-Ray Optics

- NASA MSFC

Differential deposition involves selectively depositing material on a mirror's surface, to correct low-to-mid-spatial-frequency errors inherent in the fabrication process that degrade the angular resolution of x-ray optics. MSFC originally demonstrated this technique using physical vapor deposition to correct the surface figure of small (few-cm scale) full-shell optics, intended for medical imaging. Since then, large custom systems to correct full-size optics, both full shell and segmented, have been built and characterized. Simulations and measurements show that, given adequate metrology, the technique can substantially improve the angular resolution of grazing-incidence optics. Unlike mechanical polishing, differential deposition is a non-contact figuring process. In principle then, differential deposition may be used to correct the figure of mounted, as well as un-mounted, mirrors.

This presentation will explain how the differential deposition technique is implemented, show results obtained to date, and give simulations that demonstrate the possible future potential for significantly improving x-ray optics.

21.b.14 William E. McClintock: Global scale Observations of the Limb and Disk: Observing the Earth's Ionosphere-Thermosphere with a Hosted Payload on a Communications Satellite

- University of Colorado LASP

Co-author(s): R. W. Eastes, A. G. Burns, (GOLD Science Team)

The Global scale Observations of the Limb and Disk (GOLD) is a NASA mission of opportunity that will fly an imaging spectrograph as a hosted payload on a commercial communications satellite. The mission will measure airglow emissions in the far-ultraviolet from 132 to 162 nm on a global scale to study the dynamic response of the EarthÕs Ionosphere-Thermosphere (I-T) system to external forcing by the space environment and the lower atmosphere. GOLD will employ observations of both the disk and the limb. Temperature and composition on the disk are obtained from molecular nitrogen LBH bands and atomic oxygen 135.6 nm emissions during the day, and electron density is derived from the 135.6 nm emission at night. Exospheric temperature is derived from the LBH limb emission profile, and molecular oxygen density is measured using stellar occultations. Interfacing a science instrument with a commercial communications satellite presents both challenges and opportunities that differ distinctly from those encountered with a satellite flying in a low Earth orbit and dedicated to a science mission. This presentation describes the overall GOLD architecture, including instrument design and measurement capabilities, observing scenarios, and mission operations.

22 POSTERS: 17:15 - 19:00 – Thursday, April 23

22.a Ground Posters [Lobby]

Thursday, April 23, 2015 – 17:15 - 19:00
Chair(s): E. Zesta, P. Erickson

22.a.1 Andrew Gerrard: Available Assets at the Center for Solar-Terrestrial Research

- New Jersey Institute of Technology

Co-author(s): Dale Gary, Haimin Wang, Wenda Cao, Phil Goode, Louis Lanzerotti

In this paper we will present an overview of the Center for Solar-Terrestrial Research (CSTR), which is an international leader in ground- and space-based solar and terrestrial physics, with interest in understanding the effects of the Sun on the geospace environment. CSTR is located at the New Jersey Institute of Technology (NJIT) and operates the Big Bear Solar Observatory (BBSO) and Owens Valley Solar Array (OVSA) in CA, the Jeffer Observatory at Jenny Jump State Forrest in NJ, and the Automated Geophysical Observatories (AGOs) distributed across the Antarctic iceshelf. The Center also manages a large number of instruments at South Pole Station, McMurdo Station, across South America, and across the United States. CSTR is also a PI organization in the NASA Van Allen Probes mission and houses the Space Weather Research Laboratory (SWRL), which does scientific research in the area of space weather with the mission to understand and forecast the magnetic activity of the Sun and its potential influence on Earth. Such instrumentation and data resources enable scientific studies spanning from the Sun's surface, into the Sun's extended atmosphere, and onwards into the Earth's atmosphere. Herein we review these data resources, and discuss current challenges as pertaining to "Big Data" assimilation and integration.

22.a.2 Robert Michell: Combined Radar and optical observations of meteors

- University of Maryland & NASA GSFC

Combined optical and radar observations of meteors can be used to help constrain key parameters such as the meteor ionization and luminous efficiencies. The use of high-power Incoherent Scatter Radars (ISR) is currently the primary method for observing the small signals from meteor head echoes. Using optical television rate observations of visible meteors with simultaneous radar scattering signatures make it possible to estimate meteor masses using two independent means. Radar and optical techniques for estimating meteor mass are discussed, including methods for assessing the accuracy of the mass estimates.

22.a.3 Xinzhao Chu: Very Large-Aperture High-Power (VLAHP) Lidar for Exploring the Interaction of Earth's Atmosphere with Space (OASIS 1.0)

- University of Colorado - Boulder

Co-author(s): John A. Smith, Wentao Huang, Weichun Fong, Jeffrey P. Thayer, Chester S. Gardner, Mike Hardesty, and Mike Taylor

A new initiative, namely OASIS (the Observatory for Atmosphere Space Interaction Studies), has called for a very large-aperture high-power (VLAHP) lidar as its first step forward to acquire the unprecedented measurement capabilities for exploring the space-atmosphere interaction region (SAIR) where atmospheric neutral gases become entwined with the dynamic plasma of space. SAIR is common to all planetary systems and known to be essential for sustaining life on Earth by absorbing extreme solar radiation, ablating meteoric material, regulating gaseous escape, dissipating energetic particles and fields from space, while balancing influences from the planet itself in the form of wave energy and momentum originating from the lower atmosphere. Unfortunately, there are no observations that adequately capture these properties and their influences on weather and climate.

Measurements of the neutral thermosphere are woefully incomplete and in critical need to advance our understanding of and ability to predict the SAIR. To fully explore the SAIR requires measurements of the neutral atmosphere to complement radar observations of the plasma. Lidar measurements of neutral winds, temperatures and species can enable these explorations, an objective of highest priority for the upper atmosphere science community in NRC 2013-2022 Decadal Strategy for Solar and Space Physics. Currently, there exists a serious observational gap of the Earth's neutral atmosphere above 100 km. Information on neutral winds and temperatures and on the plasma-neutral coupling in the SAIR, especially between 100 and 200 km, is either sparse or nonexistent. Consequently, our knowledge of several key processes is quite limited. Many of these topics will be addressed with the VLAHP lidar observations with unprecedented accuracy, resolution and coverage.

Discoveries of thermospheric neutral Fe, Na and K layers exceeding 170 km at McMurdo, Antarctica and elsewhere, have opened a new door to observing the neutral thermosphere with ground-based instruments. These neutral metal layers provide the tracers for resonance Doppler lidars to directly measure the neutral temperatures and winds in the thermosphere, thus enabling the VLAHP lidar dream! Because the thermospheric densities of these metal atoms are 50-1000 times smaller than the layer peak densities near 90 km, high power-aperture product lidars, like the VLAHP lidar, are required to derive scientifically useful measurements. Furthermore, several key technical challenges have been largely resolved by Dr. Chu's group through the successful development of Fe and Na Doppler lidars at Boulder that have yielded signal levels 10 times higher than any demonstrated in literature for the same power-aperture product. The VLAHP lidar will boost the lidar signals by another 10-40 times. By combining Rayleigh and Raman with resonance lidar techniques, the VLAHP lidar will be able to measure neutral temperature and wind profiles from 30 to 200 km. Future OASIS development (anticipated 100 m2 aperture size) will further enable the measurements from 300 to 1000 km. The proposed lidar is an important step towards the overarching goal – to advance our understanding of the fundamental universal processes that occur in the Earth's SAIR and how they shape the atmospheres of Earth-like planets throughout our galaxy.

22.a.4 Craig Unick: A dedicated H-Beta meridian scanning photometer for proton aurora measurement

- University of Calgary

Co-author(s): Eric Donovan, Martin Connors, Brian Jackel

An instrument designed to measure the location and brightness of auroral emissions from energetic proton precipitation is described. This photometer scans from the north to south horizon with a stepping motor and mirror. The scans are currently configured for 30 second cadence with constant dwell time versus offset at fixed height, but custom scan configurations can be accessed with software. Broadband light is separated into two channels with a novel optical splitter. This splitter uses a filter that has high transmission for the signal channel and high reflection on both the long and short wavelength sides to reflect the background passbands. The half cone angle and angle of incidence of this splitter filter allow for an overall compact optical design that also provides superior sensitivity in both signal and background channels. The signal channel is 3nm wide FWHM at 486.1nm and the background channel comprises two 3nm wide FWHM passbands at 480nm and 495nm created by a single filter. Each of these channels is measured with a photomultiplier tube (PMT) in photon counting mode. Calibration results indicate a response of around 1000 counts/s per Rayleigh. Data are currently acquired in 5ms bins with a Nyquist frequency of 100Hz, the acquisition time can be shortened to 2ms via software settings. The instrument is fully automated for operation at remote field sites. Scientific and housekeeping data are stored locally and, if possible, transmitted to a central monitoring system. The completed unit (FESO-1) has been operating at Athabasca University for more than one year, and the second system is currently undergoing field trials.

22.a.5 Alan Marchant: Etalon Imaging of Mid-Thermosphere Winds

- Utah State University

Co-author(s): Preston Hooser

We report on recent experience with a method for remote sensing of neutral wind in the mid-thermosphere utilizing red-line emission at 630.0 nm of atomic oxygen (OI-630) in the altitude range 200 - 350 km. The atmospheric scene is imaged onto a focal plane array (FPA) through a narrow-band spectral filter and a fixed-gap etalon. This simple, compact optical system creates an interferogram consisting of concentric circular fringes. The fringe amplitude is locally proportional to the spatially resolved radiance of OI-630 emission while the radial offset of the fringe is proportional to the line-of-sight Doppler shift associated with winds in the emitting thermosphere. Temperature-dependent shifts in the baseline interferogram pattern (including centration and radial phase) are tracked using an online calibration source consisting of the 630 or 633 nm emission lines of a neon glow lamp.

The etalon-based wind imager can be configured for various observing scenarios. The Split-field Etalon Doppler Imager (SEDI) images two widely separated field fields of view onto a common FPA to support triangulation of horizontal wind vectors from a CubeSat satellite platform. Alternative instrument configurations are optimized for observation from a high altitude balloon.

We report on experience with a prototype SEDI instrument. Laboratory testing using a mode-stabilized HeNe laser source and a spinning target demonstrated that the etalon imaging method is capable of resolving Doppler profiles with a sensitivity of order 10 m/s. In September 2014 the instrument was flown on a high altitude balloon with the student-led Red Line Air Glow Sensor (RLAGS) experiment. During its short flight, RLAGS demonstrated the feasibility of Doppler wind imaging and provided critical information on OI-630 radiance and background Rayleigh interference to support future thermosphere wind observing missions.

22.a.6 Qian Wu: High latitude thermospheric wind observations in the Arctic to study the magnetosphere and ionosphere interaction

- *NCAR High Altitude Observatory*

Co-author(s): William Ward

Polar cap is the region when the magnetosphere interacts more directly with the ionosphere and thermosphere through ion neutral collision and cross polar cap potential. The energy from the magnetosphere is converted into kinetic and thermal energy (via Joule heat) in the thermosphere. In order to understand the ionosphere and thermosphere response to the magnetosphere forcing, one has to know how the energy deposits into the thermosphere. Thermospheric winds are a key parameter for estimating the Joule heating. Joule heating changes the dynamics of the thermosphere, which leads to upwelling. Upwelling then changes the chemical environment of the ionosphere and decreases the ionosphere density. Enhanced by the Joule heating, the thermospheric winds push the ion-depleted ionosphere into the midlatitude region. In every step of the process, the thermospheric winds play a critical role. Hence, monitoring the thermospheric wind in the high latitude region is essential. In November 2014, two ground-based Fabry-Perot interferometers were deployed in Eureka and Resolute Canada to measure the thermospheric winds by Doppler remote sensing the O 630 nm airglow emission. For the first time, two Fabry Perot interferometers are operational inside the polar cap to provide more robust observational capability and opportunity to explore the thermosphere structure inside the polar cap. The observational results from these two instruments will be analyzed in comparison with model simulations.

22.a.7 Dadaso Shetti: Observations of Equatorial Plasma Bubble in Indian Sector by Optical and Radio Techniques

- *Smt. Kasturbai Walchand College*

Co-author(s): P.T. Patil

Simultaneous observations of OI630 nm and TEC were carried out using a CCD based All-Sky Imaging system and GPS system respectively during the month of February /April -2012 at low latitude station Kolhapur (16.8°N, 74.2°E). The radio observation of GPS is also carried out at the nearby station, Hyderabad (17.67°N, 83.32°E) and Bangalore (13.020N, 77.570E). The day-to-day variability in the occurrence of Equatorial Spread F (ESF) or Equatorial Plasma Bubble (EPB) is addressed using radio and optical observations from low latitude stations. We have found out the simultaneous occurrence of EPBs in both TEC and OI 630.0 nm emissions using both the techniques. In the present work we have also discussed the possible mechanism of day-to-day variability in the occurrence of EPBs.

22.a.8 Nicola M. Schlatter: Interferometric Radar Imaging on Svalbard

- *Royal Institute of Technology*

Co-author(s): V. Belyey, B. Gustavsson, T. Grydeland, N. Ivchenko, B. S. Lanchester

Incoherent scatter radars are powerful instruments for remote sensing of the ionospheric plasma. The derived parameters are averages over the measurement volume which is determined by the beam width in the direction perpendicular to the beam and by the transmission scheme in the beam direction. For typical incoherent scatter radars the beam width is of the order of few degrees. A large variety of ionospheric phenomena, however, occur on spatial scales smaller than the beam width. Radar interferometry allows studying the radar backscatter distribution in the plane perpendicular to the transmitting beam at scales below the beam width. At the European Incoherent SCAtter (EISCAT) Svalbard Radar (ESR) two large aperture dish antennas (32 m and 42 m diameter) are used for interferometry. EASI (ESR aperture synthesis imaging) is an extension of the one-baseline interferometer consisting of three phased array receivers each with 4 by 4 antenna elements. The interferometer is calibrated by employing radar backscatter of satellites transiting the beam. Optical observations of the satellite transits yield the angle of arrival of the radar backscatter. EASI observations of filamentary structures occurring during auroral precipitation are discussed in this talk. The filamentary structures are signatures of enhanced ion acoustic wave activity, so called Naturally Enhanced Ion Acoustic Lines (NEIALs), and occur on time scales of hundreds of milliseconds to a few seconds. Using aperture synthesis imaging techniques estimates of the 3D NEIAL backscatter distribution are obtained.

22.a.9 Philip Erickson: High-resolution sub auroral electric field measurements in the plasmasphere boundary layer

- MIT Haystack Observatory

Co-author(s): John Foster, Frank Lind

The overlap of the cold, dense plasmasphere with the hot, tenuous magnetosphere provides a rich energy source within the geospace system for a large variety of magnetosphere-ionosphere coupling processes, many of which are inherently at multiple spatial and temporal scales. During moderate to strong geomagnetic storm activity, measurement of electric field structures driven by this strong coupling can convey much information about the nature of current coupling in the Region 2 field-aligned current areas coupled to the asymmetric ring current, equatorward of the high latitude electron precipitation boundary.

During periods of strong energy exchange, the Farley-Buneman two-stream instability is a prominent resonance response to large energy input from the magnetosphere, as ions are driven at speeds up to and exceeding 1 km/s through the background ionosphere. This feedback driven mechanism creates coherent structures which strongly scatter radio waves both at fluid and kinetic regimes. In particular, at sub-meter scales, coherent radar backscatter reveals the very dynamic temporal and spatial structures of coupling electric fields. *in-situ* spacecraft measurements confirm the magnetically conjugate nature of these fields, and the combined picture provides important information on sub-auroral conductivity variations and their effects on the Region 2 system.

We review the coherent Farley-Buneman backscatter technique and will show results illuminating the variable nature of M-I coupling at sub auroral latitudes. In particular, coincident incoherent scatter and coherent scatter measurements will be highlighted to demonstrate the potential of this approach.

22.a.10 Tim Neilsen: A Radio Frequency Beacon Receiver for Detection of Ionospheric Scintillation

- Utah State University

Co-author(s): Don Thompson, Jake Gunther

The Space Dynamics Laboratory at Utah State University (SDL/USU), the Air Force Space and Missile Systems Center (SMC), and the Air Force Research Laboratory (AFRL) have teamed together to create a portable ground-based Radio Frequency beacon receiver (RFBR) system capable of characterizing ionospheric parameters, including total electron content (TEC), amplitude, and phase scintillation. The system, derived almost entirely of COTS parts, can be configured to simultaneously receive three RF beacons such as those transmitted by existing on-orbit Coherent Electromagnetic Radio Tomography (CERTO) instruments, the upcoming Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC2) instrument, or other frequencies from VHF to S-band. The RFBR team developed a very low cost ground-based beacon receiver using the latest in commercial RF and software defined radio technology. The receiver can be installed at a remote site and run autonomously. Multiple copies of this ground-based sensor are expected to be key components in future efforts for characterizing and monitoring the ionosphere and its effects on DoD communication and navigation systems. A majority of the development and lab work occurred at the SDL Logan facility, in collaboration with Air Force professionals. Multiple field campaigns to demonstrate the technology were conducted at Ascension Island (UK territory) and Logan.

22.a.11 David Themens: GPS Differential Receiver Biases in the Polar Cap Region: Investigating the nature of bias variability

- University of New Brunswick

Co-author(s): P.T. Jayachandran, Richard B. Langley, Michael J. Nicolls

The problem of receiver Differential Code Biases (DCBs) in the use of GPS measurements of ionospheric Total Electron Content (TEC) has been a constant concern amongst network operators and data users since the advent of the use of GPS measurements for ionospheric monitoring. While modern methods have become highly refined, they still demonstrate unphysical bias behavior, namely notable solar cycle variability. Recent studies have highlighted the potential impact of temperature on these biases, resulting in small diurnal or seasonal behavior, but have not addressed the, far more dominant, solar cycle variability of estimated receiver biases.

This study investigates the nature of solar cycle bias variability. We first identify the importance of the strongest candidate for these variabilities, namely shell height variability. It is shown that the Minimizations of Standard Deviations (MSD) bias estimation technique is linearly dependent on the user's choice of shell height, where the sensitivity of this dependence varies significantly from 1 TECU per 4000km of shell height error in solar minimum winter to 1 TECU per 90km of shell height error during solar maximum summer.

To assess the importance of these sensitivities, we present true shell height derived at Resolute, Canada using the Resolute Incoherent Scatter Radar (R-ISR), operated by SRI International and a Canadian Advanced Digital Ionosonde (CADI) operated by the Canadian High Arctic Ionospheric Network (CHAIN). This investigation demonstrates significant shell height variability translating to bias variabilities of up to several TECU. These variabilities, however, are found to be insufficient to account for all of the observed solar cycle variability in these biases.

To investigate these variabilities further, we next compare Total Electron Content (TEC) measurements made by a CHAIN GPS receiver at Resolute to integrated electron density profiles derived from the nearby Resolute ISR. Taking the ISR measurements as truth, we find that ISR-derived GPS receiver biases vary in the same manner as those derived using the MSD or other bias estimation approaches. Based on these results, we propose that standard receiver DCB estimation techniques may be interpreting a significant portion of plasmaspheric electron content as DCBs, resulting in apparent diurnal, seasonal, and solar cycle DCB variability.

22.a.12 Nicholas Ssessanga: Regional optimisation of IRI-2012 output (TEC, foF2) using derived GPS-TEC

- Chungnam National University

Accurate measurement and determination of the state of ionosphere has become a key-point as ground-based communication systems become more space dependent. However, due to a limited infrastructure a number of global models have been developed with extensive interpolation techniques to comprehensively describe ionospheric dynamics. As a result, most global models don't perform adequately in regions with a paucity of ionospheric measurements. In this paper, the most recent International Reference Ionosphere (IRI-2012) model output, Total Electron Content (TEC) and F2 layer critical frequency (foF2), are optimised (over a range of 120 E - 150 E and 20 N - 50 N, in longitude and latitude respectively). To obtain the optimal solution two input parameters, 12-month running mean Sun Spot Number (R12) and ionospheric index (IG12), are adjusted in relation to derived Global Positioning System (GPS) vertical TEC (VTEC). The results are compared to measured TEC and foF2 from GPS receivers and ionosondes respectively. The analysis shows that the modified IRI-2012 model is more accurate at estimating both TEC and foF2 values than the original model during geomagnetic quiet and disturbed days.

22.a.13 Hichem Mezaoui: Characterization of the Ionospheric Scintillation at High Latitude Using GPS signal

- University of New Brunswick

Co-author(s): A. M. Hamza, P. T. Jayachandran

The deterministic chaotic behavior and dynamical complexity of the space plasma in the polar region are analyzed in this study and characterized. The study was carried out using GPS (Global Positioning System) L1 signal time series. The detrending frequency of the raw GPS L1 signal sampled at 50 Hz is optimized by analyzing the behavior of the entropy of the system for different scales using the wavelet analysis. The construction of the probability density functions of the phase and amplitude fluctuations and the estimation of the corresponding higher order moments are used to quantify these fluctuations. The results reveal a general non-trivial parabolic relationship between the normalized fourth and third moments for the amplitude of the signal. A multi-fractal analysis of the power fluctuations of the L1 GPS signal is also presented. We consider the differential signal for different time lags. Probability density functions are computed and fitted with Castaing distributions. Higher order moments of the distributions are used to investigate the intermittent nature of the signal. The present work reveals a direct evidence that the intermittent aspect of the investigated events is more pronounced at small temporal scales than at long ones.

22.a.14 Chris Watson: Statistics of GPS TEC Variations in the Polar Cap Ionosphere

- University of New Brunswick

Co-author(s): P.T. Jayachandran, John MacDougall

The dynamic polar cap ionosphere is problematic for ground and satellite based communication and navigation systems, including GPS. Largely due to inadequate observational capabilities at high latitudes, generation mechanisms and source regions of polar ionospheric irregularities are not well understood. We have used five high data rate GPS receivers in the Canadian Arctic to conduct a six year statistical study of low frequency ($<$ 50 mHz) variations in GPS total electron content (TEC) in the polar cap. TEC variations at these frequencies are due to mesoscale (100-1000 kms) ionospheric density structures, which include polar cap patches and auroral arcs. Characteristics (e.g. frequency, amplitude) of TEC variations were examined as a function of magnetic local time, latitude and solar wind condition, in an attempt to link these variations to particular solar wind and magnetospheric source regions. Co-located ionosonde radars were used to estimate altitudes of ionization structures associated with the variations in TEC. F region TEC variations had a strong solar cycle, seasonal, diurnal and IMF dependence, with occurrence and amplitude peaks during the fall months, in the dayside ionosphere, and for high dayside IMF-magnetosphere merging rates. Occurrence of F region TEC variations was highly dependent on the dawn-dusk IMF orientation, with morning (afternoon) variations occurring more often for dusk-ward (dawnward) oriented IMF. Amplitude and occurrence of E layer TEC variations had a strong solar cycle, seasonal, diurnal and dayside merging rate dependence, but had little dependence on dawn-dusk IMF orientation. E layer structuring was mainly confined to the dawn, dusk and nighttime ionosphere. The frequency distribution for all TEC variations revealed peaks at 0.6, 2.0 and 4.0 mHz, with the 2.0 and 4.0 mHz peaks originating from dayside latitudes immediately poleward of the cusp. These results and their implications will be discussed.

22.a.15 Stuart Jefferies: Ground-Based Doppler and Magnetic Imaging of the Sun

- University of Hawaii

Co-author(s): Neil Murphy, Bernhard Fleck, Scott McIntosh, Thomas Straus, Wayne Rodgers

There is a growing need in solar physics to measure the 3-dimensional structure of the Sun's atmosphere, with the primary tools to do this being instruments that can measure velocity and magnetic fields at multiple altitudes. These measurements can provide insight into the transport of energy and magnetic flux in the atmosphere, the emergence of magnetic flux and helicity, the dynamics of transient phenomena such as spicules, and help constrain measurements of the magnetic field emerging into the corona. We will describe a ground-based experiment that addresses this need by measuring the line-of-sight velocity and magnetic fields at four heights, from the photosphere to the high chromosphere. The experiment comprises of four individual instruments of identical design. The heart of each instrument is a magneto-optical filter (MOF) that is used to observe the line-of-sight velocity and magnetic field signals over the visible disk of the Sun with a spatial resolution of up to 2 arc seconds and temporal resolution of 5 seconds. Each instrument observes a different height in the solar atmosphere. A proof-of-concept run with two of the instruments (equipped with MOFs using the Na 589 nm and K 770 nm solar absorption lines) at Mees Solar Observatory on Maui, showed a velocity and magnetic field sensitivity of $\sim$ 7 m/s and $\sim$5 G, respectively, in 5 seconds. We will describe the instruments, discuss their application for helioseismology and other areas of solar research, and present some initial results.

22.a.16 Daniel Whiter: A new optical method to estimate the neutral temperature at 300 km in the auroral zone

- University of Southampton

Co-author(s): Betty Lanchester[1], Bjorn Gustavsson[2], Nickolay Ivchenko[3], Hanna Dahlgren[3], Robert Fear[1]

The neutral temperature of the upper atmosphere is difficult to measure under auroral conditions. We have identified a new method which uses emissions from the excited oxygen ion O+ 2P, measured in conditions of low energy electron precipitation on Svalbard (78.20° north, 15.83° east). The ratio of the emission line doublets from O+ at 732.0 nm (I732) and 733.0 nm (I733) has been determined with high accuracy to be R = I732/I733 = 1.38 ± 0.02, which is higher than theoretical values for thermal equilibrium in fully ionized plasma. The continuity equations for the densities of the two levels are solved for different conditions, in order to estimate the possible variations of R. The results show that the production of ions from O(3P1) and O(3P2) does not follow the statistical weights, unlike astrophysical calculations for plasmas in nebulae. The physics of auroral impact ionisation must account for this difference, and therefore for the raised value of R. The important consequence of this conclusion is that the auroral solution of the densities of the ions, and thus the value of R, is sensitive to the temperature of the neutral atmosphere. This latter result means that a long data set from 2003 to the present can be used to estimate changes to the neutral temperature in the F-region under auroral conditions. The result makes it possible to determine whether there are significant variations in the ratio and hence the neutral temperature resulting from non-equilibrium conditions, from auroral energy deposition, large electric fields, and changes in composition.

22.a.17 Binod Adhikari: Geomagnetic signatures recorded on different longitudinal stations during High Intensity, Long duration, Continuous Auroral Activity (HILDCAA)

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Around the solar maximum, the dominant structures emanating from the sun are sporadic coronal mass ejection (CMEs) and their interplanetary counterparts (ICMEs). In the descending and minimum phases of solar cycle, the geomagnetic activity is mostly influenced by co-rotating high-speed streams. These high speed streams are embedded with highly fluctuated Alfvén waves. When these fluctuations of Alfvén waves in IMF (Bz) diminish, the storm starts its long recovery phase. The Earth's equatorial magnetic field monitored by the Dst (disturbed storm time) index found to be below than its quiet day value for days. This phenomena is called high-intensity, long duration, continuous AE activity or HILDCAA. In this work, we discuss the ground magnetometers signatures obtained from five longitudinal stations during three HILDCAA events of different interplanetary causes.The concepts of wavelet analysis (CWT, DWT and modulus correlation) have been used in order to get some common signatures on these stations. The CWT is an integral transform, it explores time frequency representation of the horizontal component of geomagnetic field. The objective of DWT is to highlight the disturbances associated during HILDCAA. The Daubechies orthogonal wavelet transform of order 2 with wavelet coefficient magnitudes at seven levels have been studied. In terms of wavelet coefficients the fluctuations present in the horizontal component of geomagnetic field have been analyzed.

Both CWT and DWT have proved to be an useful tool in order to get some common features on these stations during the events. We also used wavelet modulus correlation to study the correlation between H-component from five longitudinal stations with IMF-Bz. These results show that the H-component for all stations are highly correlated with IMF-Bz during HILDCAAs.

22.a.18 Titus Yuan: The Na lidar observations of mid-latitude Sporadic E layer and Sporadic Na layer in the lower E region over Logan Utah

- Utah State University

The sporadic E layer (Es) is one of the most dramatic phenomena in the upper atmosphere due to the coupling between neutral atmosphere and ionosphere. Its formation near mid-latitude (geomagnetic latitude) is most likely controlled negative zonal wind shear within the lower E region. Observations of sporadic metal layer around the globe, such as Na and K, share very similar seasonal and local time variations with the Es, implying strong associations between the two anomalies. The Na lidar at Utah State University (USU) is able to measure neutral wind and temperature, along with Na density profiles, up to 115 km during summer, when Es formation peaks. In this paper, we report the recent Es and sporadic Na (Nas) studies at USU that strengthen the wind shear theory and its association with the zonal wind variations. The in situ temperature does not seem to play important role in both anomalies. A further simulation based on climatological model results from HAMMONIA and CTMT provide a plausible connection between the seasonal and local time variations of Es and Nas, which is supported by statistical results from Utah and Beijing China.

22.b Fields Posters [Lobby]

Thursday, April 23, 2015 – 17:15 - 19:00
Chair(s): R. Pfaff, B. Anderson

22.b.1 Chrystal Moser: Design and Fabrication of a Miniaturized Fluxgate Magnetometer for the SIGMA and other Cubesat Missions

- University of New Hampshire

Co-author(s): Marc Lessard, Mark Widholm, Hyomin Kim, Ho Jin, Seongwhan Lee

Fluxgate magnetometers are often used in space because they measure vector quantities of magnetic fields with accuracy, have a relatively high radiation tolerance and their simple design consumes little power. As part of a larger mission to eventually study magnetic anomalies near the lunar surface, the University of New Hampshire will provide the Kyung Hee University in South Korea with a miniaturized fluxgate magnetometer to be integrated into the Scientific CubeSat with Instruments for Global Magnetic field and rAdiation (SIGMA) mission, a 3U CubeSat to be flown in Low Earth Orbit in 2015. One challenge with miniaturizing a fluxgate magnetometer is keeping the background noise low while retaining a minimal volume and mass. The goal of this project is to develop a new fluxgate magnetometer with a noise floor of 100 pT/$\sqrt{\text{Hz}}$ or less at 1 Hz that is small enough be mounted with an ultra-lightweight boom on a CubeSat and appropriate for scientific measurements of magnetic fields. A unique hybrid design of both a ring and a racetrack core was combined with heat-treated, permeable magnetic ribbons to make up the core materials. This design significantly reduces the volume to the order of 2x2x2 cm. Heat treatment of the Permalloy material was carried out in order to develop a larger crystal structure, with larger magnetic domains, which helps to decrease noise associated with Barkhausen jumps. The overall result is a small, lightweight magnetic sensor that operates near 0.3 Watts.

22.b.2 Werner Magnes: Magnetometer Front-end ASIC

- Space Research Institute, Austrian Academy of Sciences

Co-author(s): Hans Hauer, Aris Valavanoglou, Matthias Oberst, Harald Neubauer, Irmgard Jernej, Christian Hagen, Wolfgang Baumjohann

An Application Specific Integrated Circuit (ASIC) for magnetic field sensors based on the fluxgate principle (Magnetometer Front-end ASIC, MFA) has been developed in cooperation between the Space Research Institute of the Austrian Academy of Sciences and the Fraunhofer Institute for Integrated Circuits, Germany. It reduces the required power for the active readout electronics by a factor of 10 as well as the area needed on a printed circuit board by a factor of 3 to 4 compared to magnetic field instruments e.g. aboard Venus Express (ESA).

The concept of the MFA is based on the combination of the readout electronics of a conventional fluxgate magnetometer with the control loop of a delta-sigma modulator in order to get an optimized signal-to-noise ratio with a reasonable oversampling factor.

The analog part of the MFA contains altogether four 2-2 cascaded sigma-delta modulators. Three of those modulators are having the fluxgate sensor in their control loops for a direct analog-to-digital conversion of the sensor output. The fourth modulator is unmodified and connected to the output of an eight-to-one multiplexer for housekeeping measurements (e.g. temperatures of MFA and fluxgate sensor). The single-bit outputs of the cascaded modulators are processed by a digital tuning logic for generating a fourth-order noise shaped and digitized output signal. The digital part includes primary (128 Hz output) and secondary decimation filter stages (2, 4, 8, to 128 Hz output) as well as a serial synchronous interface which enables data transmission with 24 bit resolution. The chip area (350nm CMOS from ams AG) is about 20 mm^2 and the total power consumption is 60mW (drive power for the fluxgate sensor is not included).

The achieved performance and radiation robustness can be summarized with THD $>$ 95 dB, SNDR in field mode $>$ 85 dB, offset stability $<$ 10 pT/degC and $<$ 0.2 nT/100h, SELth $>$ 12 MeV/cm^2/mg and TID $>$ 300 krad. A first space magnetometer with the MFA connected to a fluxgate sensor built by the University of California, Los Angeles was built for the 4-satellite Magnetospheric Multiscale mission (launch in March 2015).

22.b.3 Harri Laakso: Usage of dual fluxgate technique for the removal of strong solar array disturbances and telemetry errors

- ESA

The Double Star mission was the first scientific mission done in collaboration between ESA and Chinese National Space Agency. The purpose of the mission is to study, together with the four Cluster spacecraft, physical processes in the Earth's magnetosphere. The mission consists of two high-altitude polar-orbiting satellites (TC-1 and TC-2), launched in Dec 2003 and Jul 2004, respectively, and were operational for about four years. Each satellite carries 8 experiments where some of them were flight spares of Cluster experiments, including the dual Flux-Gate Magnetometer on TC-1. Due to a wrong wiring of the solar power control system on TC-1, very large and highly variable magnetic interferences (20-30 nT) occur in the magnetic field measurements; with help of European expertise, the wiring was corrected for TC-2 in spring 2004 before its launch. In addition the observations from both spacecraft suffer from frequent random telemetry errors that affect the quality of the measurements as well. Due to these two problems the magnetic field measurements available to the community has been limited.

Due to the importance of the magnetic field measurements, the Cluster Active Archive (CAA) project at ESTEC decided to make an effort on cleaning the magnetic field measurements using a dual fluxgate technique. The magnetic interferences on TC-1 are highly variable and depend on the range value of the analogue fluxgate and the shunting system of the spacecraft solar power control system. The processing algorithms developed by the CAA team help to reduce the noise from 20-30 nT variations down to a level of 0.2-0.3 nT that allows a full exploitation of the magnetic field observations for most of the time. All measurements have been cleaned and the data have been made available via the Cluster Science Archive. The presentation shows the main processing steps required for (1) removing the highly varying magnetic interferences produced by the solar arrays and solar power control system and (2) detecting and removing telemetry errors.

22.b.4 Robert Pfaff: Critical Review of Double Probe Electric Field Experiments Flown on Sounding Rockets

- NASA GSFC

Co-author(s): Doug Rowland, Henry Freudenreich

For over five decades, electric field double probes have been flown on sounding rocket missions, returning a wealth of DC and AC potential differences that are associated with the core processes of numerous low, mid, and high latitude Geospace phenomena. The technique works exceedingly well over a large range of plasma density, temperature, and composition values, providing high quality measurements from the mesosphere to altitudes of over 1000 km. Successful double probe experiments have been flown on sounding rocket payloads using a variety of deployment systems, which typically have extended spherical sensors near the ends of stacer, wire, and fiberglass booms with tip-to-tip sphere separation distances ranging between 3-8m. Bare cylindrical tip sensors have also been used to gather high quality DC and AC electric field measurements. In some cases, inner sets of spheres ("double-double probes") have been flown to provide independent sets of vector electric field measurements on the same payload. Such dual sensor configurations also yield direct measurements of the plasma sheath around the payload (and how it changes with plasma density) as well as spaced receiver or wave interferometer measurements. Double probe data gathered on sounding rockets have included measurements of a wide variety of natural phenomena, including DC convection and polarization electric fields, lightning pulses, irregularities, and a large assortment of plasma waves, ranging from Alfvén waves to VLF whistlers to HF Langmuir waves.

This talk presents a critical review of double probe measurements gathered on sounding rockets. Whereas the measurements are generally quite robust at high latitudes, where the plasma density is generally high and the ambient fields are large, at low and mid-latitudes, where the ambient electric fields may be only a few mV/m or smaller, the accuracies are less certain. In particular, charging and sheath effects appear as non-geophysical contributions to the measured potentials, and errors due to ACS gases, wakes, and non-conducting booms may appear in even the most careful analysis. Low altitude measurements ($<$ 100 km) are particularly challenging at all latitudes where the plasma density is significantly reduced. In general, the observations underscore the need for long, conducting, symmetric booms and sensors, particularly where high precision measurements are critical. We review the necessary experimental elements that appear to be most critical for gathering successful double probe measurements at all altitudes and latitudes.

22.b.5 Douglas Rowland: Atomic Oxygen-Resistant Coatings for Electric Field Sensors

- NASA GSFC

Co-author(s): R Pfaff, A Boddapati, J Klenzing, M Beamesderfer, C Hoffman, M Choi, S Miller, B Banks, E Sechkar, D Walters

Double-probe electric field instruments function by measuring the voltage difference between a pair of probes, separated by a suitable baseline, d, that are immersed in a plasma. Vector measurements of the electric field are obtained by gathering data from three mutually orthogonal double-probe pairs. The probe surfaces must be as uniform and stable as possible in order to minimize measurement errors. In particular, work functions which are spatially varying on a single probe, varying between matched probes, or variable with time or exposure to the space environment can produce errors which are dependent on the aberrated ram angle of the spacecraft. For typical surfaces (baked-on carbon coating (DAG 213) or titanium nitride), these errors can approach tens to hundreds of mV, and when divided by the length of the measurement baseline, can result in electric field measurement errors of a few to several tens of mV/m. Atomic oxygen erosion, particularly in carbon, has been identified as a potential problem for double-probe instruments flown to altitudes below 300 km.

For a spinning spacecraft, these work function offsets can often be removed by a simple sine fit to the spin-plane data, but for the spin axis data as well as for three-axis stabilized spacecraft of the type commonly used in the ionosphere, these offsets can only be removed by more extensive analysis. When the surface treatments of the probes are time-stable, this offset removal can be done quite routinely and to a high level of accuracy, as verified by the C/NOFS data analysis and as validated with offset determination during occasional spacecraft spins. On the other hand, if the probe surfaces were to exhibit work function variability on short timescales, for example, under brief exposure to heavy atomic oxygen (AO) levels encountered below about 200 km, the offset removal techniques would not be as effective.

To better understand the effects of atomic oxygen on commonly used double-probe sensor coatings, we performed a study of the changes in surface properties after several different levels of atomic oxygen exposure. The surfaces tested include colloidal graphite (DAG 213), gold, aluminum titanium nitride (AlTiN), titanium nitride, and molybdenum. Coupons with these coatings were subjected to atomic oxygen fluence levels ranging from 10^{20} to 3.77 x 10^{22} AO / cm^2. These levels range from those encountered by typical topside ionospheric satellites (e.g., 500 km circular orbit) over a multi-year mission to a case similar to what would be observed for a satellite with perigee occasionally reaching 150-200 km for weeks at a time.

We performed a comprehensive set of measurements to assess surface properties and stability as a function of AO exposure, including thermal properties (alpha/epsilon), surface roughness, surface conductivity, work function mapping, SEM, and XPS to determine chemical changes under AO exposure.

Of the surfaces treated, aluminum titanium nitride had the best combination of favorable (and stable) thermal properties, and relatively stable and uniform work function with AO exposure. It also exhibited less chemical modification than the usual standard surface treatment, titanium nitride. AlTiN thus appears to be a good candidate for double probe sensors in a high atomic oxygen fluence environment.

22.b.6 Paul A. Bernhardt: CARINA: A Mission to Demonstrate Global Measurements of Fields and Particles From Low-Drag Satellites Flying Below the F-Region Ionosphere

- Naval Research Laboratory

Co-author(s): Carl L. Siefring, Paul Oppenheimer

An evolutionary step in ionospheric research is the Naval Research Laboratory CARINA mission where multiple spacecraft are put into limited life (45 to 60 day) earth orbits (LLEO) in the 150 to 250 km altitude range. Previous space missions have used either short-duration, sounding rockets in the 0 to 1000 km altitude range or long-duration, low-earth-orbit satellites with average altitudes above 300 km. The NRL CARINA satellites will explore the lower thermosphere with direct, *in situ* observations and will be able investigate both sporadic-E layers below the satellite and F-region structures above the satellite using radio propagation from ground and space based RF sources. The CORINA satellites look like torpedoes with have large mass (200 kg) and low drag area (0.05 sq-m). The sensors for the first CARINA mission are the orbiting GPS receiver (OGR), ram Langmuir probe (RLP) and an electric field instrument (EFI) covering the high frequency (2 to 15 MHz) range. The unique measurements with the CARINA satellite include (1) direct fly-through of the regions of the ionosphere modified by high power radio waves, (2) tomographic mapping Sporadic-E layers using ground HF radio beacons, (3) detection of the ionospheric coupling of extreme ocean storms using HF radar surface wave sea scatter to the CARINA receiver, (4) monitoring of traveling ionospheric disturbances in the lower thermosphere by employing *in situ* plasma probes and orbiting GPS TEC receivers, and (5) detecting electric field transients from terrestrial lightning that can drive space-plasma fluctuations. Subionospheric satellite experiments will expand the knowledge of lower thermospheric science at all latitudes and enhance our understanding of the direct coupling between large scale terrestrial disturbances and bottomside ionosphere.

22.b.7 Carl Siefring: High Impedance Measurements of HF Waves in Space Plasmas with Modern Digital Receivers

- Naval Research Laboratory

Co-author(s): David Blackwell, Paul Bernhardt, George Gatling, David Walker, Richard Fernsler, Gordon James

Measurements of HF waves, up to 10s of MHz, in space plasmas can be performed similar to DC/VLF electric field measurements by using high-impedance amplifiers and spherical or cylindrical sensor elements. Modern digital receivers allow recording of highly accurate broadband or narrow-band downconverted signals and allow for detailed analysis of wave properties that would have been difficult or impossible in the past. HF measurements are complicated due to various plasma resonances, wave modes and wave lengths, and the antenna/plasma coupling impendence characteristics in this frequency range. Of particular interest are measurements of large amplitude HF electromagnetic waves from ionospheric heating facilities such as HAARP, SURA or EISCAT and a host of non-linear plasma effects that are driven by these electromagnetic waves. We will discuss the theory and practice of making these measurements, including non-linear antenna coupling, methods to discriminate between long wavelength electromagnetic waves and short wavelength electrostatic waves, and recent measurements over the HAARP facility with the Radio Receiver Instrument (a digital receiver) on the Canadian CASSIOPE/ePOP satellite.

This work was sponsored by the Naval Research Laboratory base program.

22.b.8 Baptiste Cecconi: Space based low frequency interferometric radioastronomy: the path towards the imaging of the inner heliosphere.

- LESIA Observatoire de Paris

Low frequency radioastronomy observatories for the heliosphere have been using similar instrumentation for decades. The Cassini, STEREO, and the future Solar Orbiter mission are embarking goniopolarimetric radio receiver connected to 3 electric wire antennas. Such instrument provides the spectral matrix (or part of it) from which the wave parameters can be derived. They require a point source assumption (plane wave) to derive the direction of arrival of the wave, the polarization and the flux density. In case of a spatially extended source (disk shaped, with a given radial profile), the source centroid direction and the apparent source size can also be derived. This type of instrumentation cannot provide much more parameters, as there is a maximum of to 9 independent measurements for each time-frequency step (i.e. an instantaneous set of measurements). Radio maps can be produced a posteriori combining consecutive data at the cost of averaging out small scale temporal variations. Furthermore, these inversion do not allow solving for several sources, or for complex source geometry.

We present a concept of radioastronomy instrumentation using a swarm of small satellites (possibly cubesats) with sensitive radio receivers measuring the wave front and phase of the radio waves on each spacecraft. This instrument will also provide 3-dimensional interferometric measurement from which real imaging capabilities will arise, as it is now occurring on ground at frequencies above 15 MHz, with the LOFAR interferometer in Europe, or the LWA in the USA. The proposed concept will be very complementary to these instruments, as they will be operating from a few kHz to a few 10 MHz from space, and thus not affected by the ionospheric cutoff at 10 MHz.

Such resolved imaging capabilities of the inner heliosphere would be a real step forward to better understand the radio emissions mechanisms and the energetic at the origin of the radio sources, as well as the propagation processes. We will present the various existing projects and the roadmap to reach this goal.

22.b.9 David Malaspina: Analog and Digital Signal Processing on the Digital Fields Board for the FIELDS instrument on the Solar Probe Plus Mission

- University of Colorado / LASP

Co-author(s): Robert Ergun, Mary Bolton, Mark Kien, David Summers, Magnus Karlsson, Vaughn Hoxie, Alan Yehle, Ken Stevens, Stuart Bale, Keith Goetz

The first *in-situ* measurements of electric and magnetic fields in the near-Sun environment ($<$ 0.25 AU from the Sun) will be made by the FIELDS instrument on the Solar Probe Plus mission. The Digital Fields Board (DFB) is a receiver within FIELDS that performs analog and digital signal processing, as well as digitization, for signals between DC and 60 kHz from five voltage sensors and four search coil magnetometer (SCM) axes. These nine input signals are processed on the DFB, through application of DC and AC coupling, anti-aliasing filters, and gain stages, into 26 analog data streams. A specialized ASIC performs 16-bit analog to digital conversion on all 26 analog channels simultaneously at 150,000 samples per second. The DFB then processes the digital data using a field programmable gate array (FPGA), generating a wide variety of data products, including digitally filtered continuous waveforms, high-rate burst capture waveforms, power spectra, cross-spectra, band-pass filter data, and several ancillary products. While the data products are optimized for encounter-based mission operations, they are also highly configurable, a key design aspect for a mission of exploration. This presentation will discuss the board design and data processing techniques used to ensure that the DFB produces high quality science data, using minimal resources, in the challenging near-Sun environment.

22.b.10 Deirdre Wendel: Using Multiple Magnetometer Data in a Tetrahedron Formation to Derive Instantaneous Magnetic Geometries and Velocities in Space

- NASA GSFC

Co-author(s): Patricia H. Reiff, Mark L. Adrian

We present a technique of using multiple spacecraft magnetic field measurements to produce a two or three-dimensional instantaneous snapshot of the magnetic field structure around a region within the spacecraft tetrahedron where a linear approximation holds. The method can also be used to derive the absolute position and velocity of the structure. This allows the computation of particle velocities in the rest frame of the structure. Comparing to alternative methods of determining the absolute velocity of magnetic structures yields further information about the stationarity and linearity of the structure. We will demonstrate the method on actual Cluster spacecraft encounters with two-dimensional and three-dimensional magnetic structures.

22.b.11 Jan Soucek: On-board processing of waveform measurements implemented in the Time Domain Sampler module of Solar Orbiter RPW instrument

- Institute of Atmospheric Physics

Co-author(s): Ludek Uhlir, Radek Lan, Ivana Kolmasova, Ondrej Santolik, Milan Maksimovic

The Radio and Plasma Wave (RPW) instrument of the Solar Orbiter spacecraft will include a Time Domain Sampler module (TDS) dedicated to electromagnetic waveform measurements from about 200 Hz to 200 kHz. The primary science objective of the instrument is *in-situ* measurement of solar wind Langmuir waves associated with solar bursts and interplanetary shocks and the process of their conversion to electromagnetic radiation. Langmuir waves are observed at a relatively high frequency (10-100 kHz) and appear in the form of short modulated wave packets. A secondary science objective of TDS is the detection voltage spikes often observed on electric field antennas as a result of an impact of dust particle on the spacecraft. Both phenomena are relatively rare and the data volume associated with the measurement is very large. On board detection and pre-processing of the data can thus reduce the required telemetry bandwidth and increase the science return of the experiment.

The instrument implements an advanced on-board digital signal processor dedicated to pre-processing of captured waveform data by configurable digital filters and basic analysis of waveform snapshots (identification of wave packets and electric field signatures of impacts of dust particles on the spacecraft, calculation of basic signal characteristics). The results of the on-board analysis are used to select interesting wave events for downlink and to collect statistics on observed snapshots which cannot be transmitted to ground. The data filtering and decimation are implemented in FPGA firmware and the more complicated data processing is performed in software running on Leon3-FT CPU.

We present the design and performance of the instrument hardware, overview of the algorithms used in event identification, and the assessment of their performance on test datasets based on measurements from STEREO spacecraft.

22.b.12 Micah Dombrowski: An Autonomous Receiver/Digital Signal Processor Applied to Ground-Based and Rocket-Borne Wave Experiments

- Dartmouth College

Co-author(s): Micah Dombrowski, Jim LaBelle, David McGaw, Matt Broughton, James Vandiver, Spencer Hatch

The programmable combined receiver/digital signal processor (Rx-DSP) platform presented in this article is designed for digital downsampling and processing of general waveform inputs with a 66 MHz initial sampling rate and multi-input synchronized sampling. Systems based on this platform are capable of fully autonomous low-power operation, can be programmed to preprocess and filter the data for preselection and reduction, and may output to a diverse array of transmission or telemetry media. We describe three versions of this system, one for deployment on sounding rockets and two for ground-based applications. The rocket system was flown on the CHARM-II mission launched from Poker Flat Research Range, Alaska, in 2010. It measured auroral "roar" signals at 2.60 MHz. The ground-based systems have been deployed at Sondrestrom, Greenland and South Pole Station, Antarctica. The Greenland system synchronously samples signals from three spaced antennas providing direction finding of 0-5 MHz waves. It has successfully measured auroral signals and man-made broadcast signals. The South Pole system synchronously samples signals from two crossed antennas, providing polarization information. It has successfully measured the polarization of AKR-like signals as well as auroral hiss. Further systems are in development for future rocket missions and for installation in Antarctic Automatic Geophysical Observatories.

22.b.13 Eftyhia Zesta: Distributed Acquisition for Geomagnetic Research (DAGR) for SmallSats

- NASA GSFC

Co-author(s): Todd Bonalsky, Deirdre Wendel, David Simpson, Ted Beach, Lindsay Allen, Odile Clavier

Geomagnetic field measurements are a fundamental, key parameter measurement for any space weather application, particularly for tracking the electromagnetic energy input in the Ionosphere-Thermosphere system and for high latitude dynamics governed by the large-scale field-aligned currents. The full characterization of the Magnetosphere-Ionosphere-Thermosphere coupled system necessitates measurements with higher spatial/temporal resolution and from multiple locations simultaneously. This becomes extremely challenging in the current state of shrinking budgets. Traditionally, including a science-grade magnetometer in a mission necessitates very costly integration and design (sensor on long boom) and imposes magnetic cleanliness restrictions on all components of the bus and payload. Recent advances in Smallsat and Cubesat developments offer a pathway for the proliferation of measurements. However, the Cubesat bus is a small volume in which to include all traditional bus components and payload, and the low cost of such programs makes the acquisition of clean Geomagnetic field observations a challenge. This work presents our approach of combining multiple sensitive onboard sensors with an innovative algorithm approach that enables high quality magnetic field measurements in Cubesats.

22.b.14 Robert Marshall: Electric and Magnetic Field Measurements on the VPM CubeSat

- Stanford University

Co-author(s): Ivan Linscott, Austin Sousa, Steven Ingram

The VLF Wave and Particle Precipitation Mapper (VPM) CubeSat, scheduled for launch in 2016, is designed to measure electromagnetic waves and relativistic electrons from low earth orbit. The payload instruments include an electric field dipole antenna, a magnetic field search coil, and two electron detectors, designed to measure electrons from 100 keV to 1 MeV in 16 log-spaced energy bins. In this talk we focus on the design of the field sensors and associated electronics and data processing. The electric field dipole antenna is a 1-meter antenna deployed as a tape spring. The magnetic field search coil, provided by the Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E), includes a preamplifier circuit, and is sensitive to fields from 100 Hz to 30 kHz. Both electric and magnetic field signals are then fed to single-chip low-noise amplifiers (LNAs) and analog-to-digital converters (ADCs) that were designed at Stanford specifically for space-based measurements. These form a single-board CubeSat VLF receiver with SFDR $>$ 60 dB and minimum sensitivity of 10 fT/root-Hz (magnetic field). Outputs of the ADC, sampled at 80 kS/s, are fed to an FPGA-based Data Processing Unit (DPU). The DPU â "completely realized in firmware" produces both burst-mode and survey-mode data. The survey data are comprised of 512-point spectra from 0 to 40 kHz, output every 30 seconds. Burst data events of 30-second duration can be selected with a variety of options, including time domain or frequency domain outputs, windowing, temporal decimation to 5, 10, 20, or 40 kS/s, and/or frequency bin selection. As of March 2015, the engineering model (EM) of the payload has been completed, and the flight model is under assembly and test.

22.b.15 Shahriar Esmaeili: Extracting Kink-like Modes of Multi-Stranded Loops in The Solar Corona

- University of Zanjan

Co-author(s): Shahriar Esmaeili, Mojtaba Nasiri, Neda Dadashi, Hossein Safari

Collective transverse coronal loop oscillations seem to be detected in observational studies. Recently, the transverse oscillations of multi-stranded coronal loops composed of several parallel cylindrical strands are investigated. This paper investigates the kink-like modes of a multi-stranded coronal loop in the presence of longitudinal density stratification along the loop axis. Monolithic loops that have kink frequencies oscillate with a frequency which is slightly different from their similar multi-stranded loops. The MHD equations are reduced to solve a set of nine-stranded loop and their equivalent monolithic loop. The governing equation are solved numerically using Finite Element Method. Eigenfrequencies and eigenfunctions are extracted.

22.b.16 George Hospodarsky: Space Based Search Coil Magnetometers

- University of Iowa

Search coil magnetometers are one of the primary tools used to study the magnetic component of low frequency electromagnetic waves in space. Their relatively small size, mass, and power consumption, coupled with a good frequency range and sensitivity, make them ideal for spaceflight applications. The basic design of a search coil magnetometer consists of many thousands of turns of wire wound on a high permeability core. When a time-varying magnetic field passing through the coil, a time-varying voltage is induced due to Faraday's law of magnetic induction. The output of the coil is usually attached to a preamplifier, which amplifies the induced voltage and conditions the signal for transmission to the main electronics (usually a low frequency radio receiver). Search coil magnetometers are usually used in conjunction with electric field antenna to measure electromagnetic plasma waves in the frequency range of a few Hz to a few tens of kHz. On a spinning spacecraft, they are also sometimes used to determine the background magnetic field. In fact, the first search coil flown by the United States was on Pioneer 1 in 1958, designed to determine the strength of the interplanetary and possible lunar magnetic field, with an upper frequency limit of only a few Hz. Search coil magnetometers are used to determine if the detected emissions are electrostatic or electromagnetic, and to investigate wave propagation parameters, such as Poynting and wave normal vectors. The University of Iowa has a long history of designing, building, and flying search coil magnetometers to investigate low frequency plasma waves, starting with Explorer 50 (IMP-J) in 1973, and continuing with search coils on the Hawkeye, ISEE, DE, PDP, CRRES, Wind, Polar, and most recently on the Van Allen Probes and Juno spacecraft. We will present some of the basic design criteria of search coil magnetometers and discuss in detail our recent Van Allen Probes and Juno designs and capabilities.